OPERATING AND SERVICE INSTRUCTIONS

WITH PARTS LIST

PHASE ANGLE VOLTMETER

MODELS 213B & 213C

NORTH ATLANTIC

industries, inc.

GENERAL ELECTRIC
INSTRUMENTATION & COMMUNICATION
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OPERATING AND SERVICE INSTRUCTIONS

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PHASE ANGLE VOLTMETER

MODELS 213B & 213C

Circuits in this instrument are covered under
Patent No. 3,267,358, 1,060,991 and 780,031.

NORTH ATLANTIC INDUSTRIES, INC.
Hauppauge, New York

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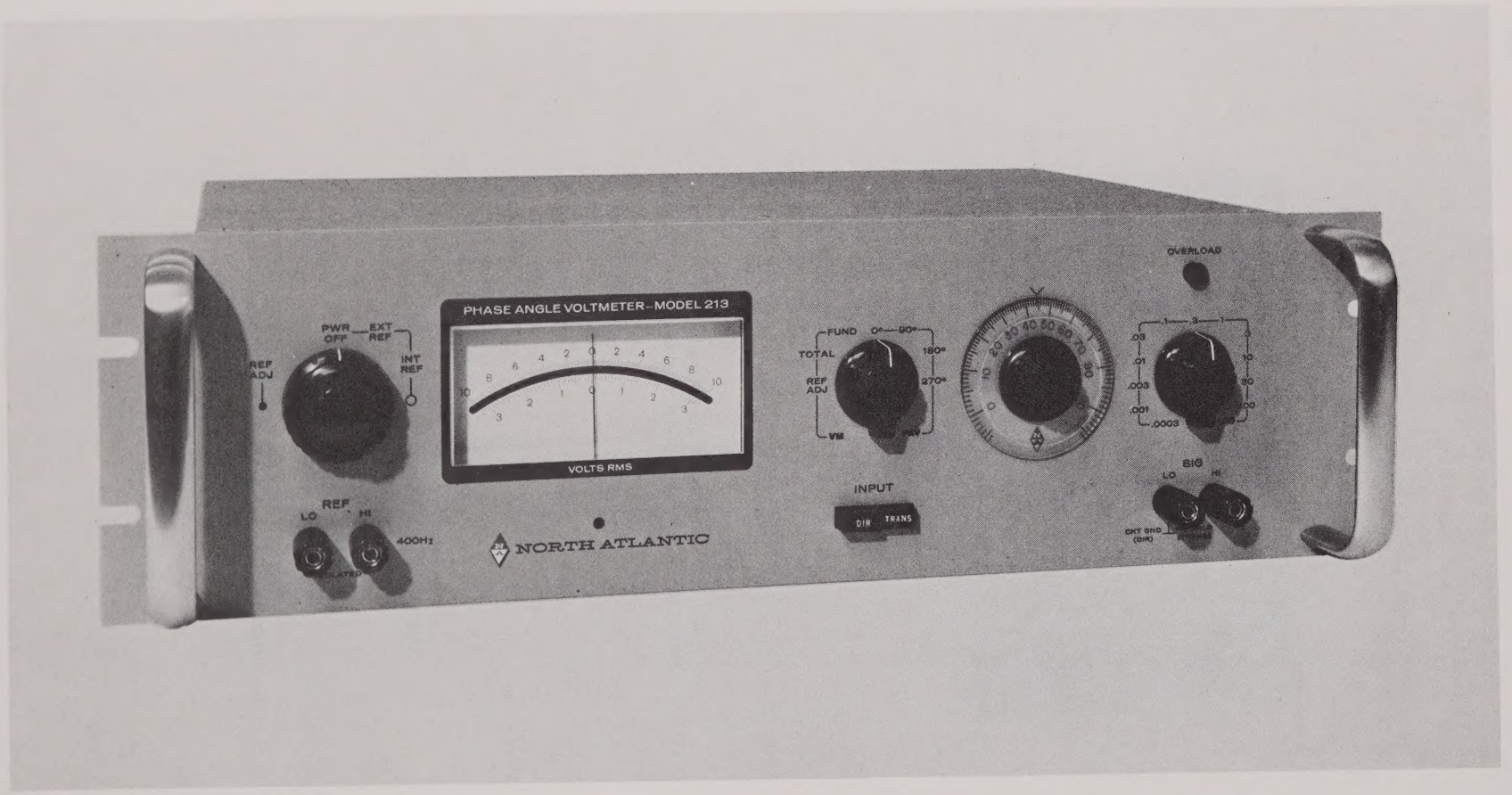
PHASE ANGLE VOLTMETER—MODEL 213
PWR OFF
EXT REF
INT REF
REF ADJ
VOLTS RMS
FUND
TOTAL
REF ADJ
0°—90°
180°
270°
VM
OVERLOAD
REF
LO
HI
400Hz
NORTH ATLANTIC
INPUT
DIR
TRANS
SIG
LO
HI
CKT GND (DIR)

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CAUTION

High voltage exists at several points in the instrument. Normal precautions consistent with good practice should be taken to reduce shock hazard.

A potential shock hazard exists when ungrounded power source or ungrounded case operation is employed. Persons operating the instrument should be made aware of, and take precautions against, this condition.

North Atlantic Industries, Inc. cannot be held responsible for damage to person or property in the process of, or as a result of, operation, maintenance, calibration, or setting up of the instrument.

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SECTION I

1.1 INTRODUCTION AND DESCRIPTION.

The Model 213 Phase Angle Voltmeter is a completely transistorized instrument which combines the ability to measure both phase angle and magnitude of complex AC signals and vector components with respect to a reference voltage. Designed for phase sensitive operation at a pre-specified frequency within 30Hz to 10KHz, it utilizes passive phase-shifter circuits to assure long-term stability and high accuracy over the spectrum. Front-panel controls permit instantaneous selection of range and function.

As a TOTAL voltmeter, the Model 213 is capable of measuring signals within a frequency range of 10Hz to 100KHz. The Model 213C has its frequency response limited to that of the signal isolation transformer. The signal input voltage, in the transformer mode, is limited to .75f. (f = signal frequency in Hertz)

As a phase-sensitive null meter, the Model 213's 2μV nulling sensitivity permits high-resolution ratio-metric measurements. This allows measurement of low-level voltages of the reference frequency in the presence of noise, hum, and other spurious signals. As a phase meter, angles are read on a parallax-free scale calibrated in 1° increments.

The Model 213 is available in two basic configurations:

1.2 MODEL 213B - REFERENCE ISOLATION BUT NO SIGNAL ISOLATION.

The Model 213B will perform all the basic functions for which the instrument has been designed, except that it does not contain any means for isolating signal inputs.

1.3 MODEL 213C - BOTH REFERENCE AND SIGNAL ISOLATION.

The Model 213C differs from the Model 213B not only by the addition of signal isolation, but it also includes a front panel switch for switching the transformer in or out of the signal input circuit. Note: Input voltages in the transformer mode are limited to .75f. (f = signal frequency in Hertz)

1.4 APPLICATIONS.

A. Phase-Sensitive Null Indicator

B. Measures separately the in-phase and quadrature components of an AC signal.

C. Measures phase shift in any AC system.

D. Sensitive AC electronic voltmeter

E. Testing of servos, computers, synchros, resolvers, inductosyn.

F. Precise AC ratiometry

G. Phasing of servo motors, chopper amplifiers, magnetic amplifiers.

H. Measuring both torque and non-torque producing signals in servo amplifiers.

I. Align carrier amplifier and notch networks

J. Impedance meter

K. Power factor meter

L. Measuring response of vibrational system.

Detailed descriptions of these applications are shown in the Application Notes in Section VIII.

1.5 GENERAL SPECIFICATIONS.

The following specifications apply to all North Atlantic Models 213B and 213C Phase Angle Voltmeters. Where a special modification or variation is involved, the governing specification will either be a separate specification control document, the purchase order, or a supplement contained in this manual. Specifications for individual instruments are always identified by a specification "S" number appearing on the instrument nameplate - e.g. 213B-S1234.

Voltage Range (Full-Scale Output)	300μV to 300V in 13 ranges
Frequency Ranges	Total Mode - Direct Input: 10Hz to 100KHz 213C Only - Trans. Input: 20Hz to 3KHz*

*Typical for pre-specified phase sensitive frequency of 400Hz.

Frequency Ranges (Cont'd)	Fundamental and Phase Sensitive Modes - Single prespecified frequency with ±5% bandwidth in a range between 30Hz and 10KHz.
Voltage Accuracy	Total Mode - Direct Input: ±2% of Full Scale, 20Hz to 50KHz ±5% of Full Scale, 10Hz to 20Hz 50KHz to 100KHz 213C Only - Trans. Input: ±2% of Full Scale, 60Hz to 2KHz* ±5% of Full Scale, 20Hz to 60Hz, 2KHz to 3KHz Fundamental and Phase Sensitive Mode - ±2% at phase sensitive frequency of operation.
Phase Accuracy:	±1° as read on the Calibrated Phase Dial, ±3% Full Scale Angle using E cos θ characteristic (See Application Notes)
Calibration:	Voltage - Zero center, low stiction meter calibrated 3-0-3 and 10-0-10 scales Phase Dial - Continuously calibrated in 1° increments from -6° to +96° over four quadrants 0°, 90°, 180°, 270°. Resolution - 0.2°
Signal Input Impedance:	Model 213B - 10 megohms shunted by 65$\mu\mu$f nominal. (140$\mu\mu$f with rear input terminals) Model 213C Direct Mode: 10 megohms shunted by 75$\mu\mu$f nominal (150$\mu\mu$f with rear input terminals) Transformer Mode: 300K Min at 400Hz
Reference Input Impedance	300K Nom. (100K Nom. for frequencies below 400Hz)
Reference Input Voltage:	Model 213B, 213C: 1.5V to 200V max., 400Hz to 10KHz; 3.8V to 200V max. below 400Hz.
Signal Input DC Voltage Level:	Model 213B - 400V max. Model 213C Transformer Mode: 0V (with no external blocking capacitor) Direct Mode: 400V
Transformer Common Mode Rejection: (at 400Hz)	Zero Source Impedance: .0025% max. 1K Source Impedance: .004% max. (1K in series with high input) .006% max. with rear input terminals
Overload:	10 x full scale signal input overload light will completely ignite at approximately 12 x full scale setting.
Noise:	Less than 15μV, Total and Fundamental Modes.
Nulling Sensitivity:	Less than 2μV, Phase Sensitive Modes.
Fundamental Mode Frequency Response:	See Diagram, Figure 4.4

*Typical for pre-specified phase sensitive frequency of 400Hz.

Harmonic Rejection:	At 400Hz; 55DB
Phase Sensitive Modes	All Other Frequencies of Operation
	40DB to 70DB depending on frequency of operation - see Diagram, Figure 4.4.
Non-Coherent Signal Rejection:	For frequencies removed from signal frequency by approximately 5Hz or more (effective pass band of meter movement), response is essentially zero for levels up to 10 x the value of the full-scale range in use. Internal filters will increase the allowable level of the non-coherent signal to 300 x the value of the full-scale range in use on the most sensitive ranges, provided the non-coherent signals are in the stop band of the filter.
Power:	115V/125V or 230/250V ±10% - 45-440Hz-10VA
Fuse:	For 115/125V Power: .5A, type 3AG. S.B.
	For 230/250V Power: .25A, type 3AG. S.B.

1.6 MECHANICAL SPECIFICATIONS.

Size:	Panel is 5-1/4" x 19" W.
	Depth behind panel: 12"
	Width behind panel: 16-3/4"
Weight:	Approximately 15 lbs.
Mounting:	Rack or bench mounted.
Front Panel Paint:	Semi-Gloss Gray #26280
Line Cord:	6' long with ground pin.
Front Panel Input:	Inputs are standard, 5-way binding posts, spaced on 3/4" centers.

Specifications subject to change without notice.

SECTION II

PREPARATION FOR USE

2.1 REMOVAL FROM PACKAGE.

This instrument has been thoroughly tested, inspected, and evaluated at the factory prior to shipment. Particular care has been taken in the design of the special wrapping and packaging material used in the container to ensure that no damage results from the typical handling encountered during shipment. However, upon removal from the package, the instrument should be externally inspected for any obvious damage. Should such damage be observed, refer to the Warranty in Section VIII. The instrument may now be mounted (either rack or bench) and checked per Performance Evaluation Procedure. (Paragraph 5.5)

SECTION III

OPERATING INSTRUCTIONS

3.1 METER ZERO.

Prior to making any connection, check the meter to see that it reads 0. If it does not, reset the meter to read 0 by means of the Zero Adjust screw which may be reached through a hole below the meter on the front panel. This adjustment must be done with the power off, and with the instrument in the normal horizontal or near horizontal position.

3.2 POWER LINE VOLTAGE.

The Model 213 is normally wired for 115V/125V operation with switch S6 in the 115V position. If it is desired to operate the instrument from a 230V/250V source, remove the top cover and switch S6 to 230V position.

Note

Be sure to use the proper fuse for the desired operating voltage. 115V/125V source will be .5 amp., type 3AG fuse, and 230V/250V source will be .25 amp., type 3AG fuse.

3.3 GROUNDING.

All electrical circuits and power grounds are floating (in the Direct Mode) with respect to the chassis. The instrument is supplied with a three-prong power plug. The round pin is wired to the chassis. Common grounding of power, chassis, and circuit ground is accomplished by means of a link on two rear panel terminals, one of which is chassis Ground, and the other input circuit Ground. The circuit ground must be connected to chassis ground either at these terminals or remotely.

Circuit Ground is automatically tied to chassis Ground in the Transformer Mode independent of the link connection. Dependent upon specific application, it may be more desirable to wire the chassis such that it is not connected directly to house ground. In those cases, extreme caution must be taken to avoid any personal injuries due to the resultant shock hazard. As a general rule, every effort must be made to ensure that the chassis is wired to a house ground at all times.

Great care should be given to grounding methods used to avoid ground loops and stray fields.

3.4 LOW FREQUENCY, HIGH-LEVEL VOLTAGES.

When the instrument is operated in the Transformer Mode (Model 213C), care must be taken not to apply high-level voltages at a low frequency such that the 0.75f (f = Hz) maximum voltage rating of the input transformer is exceeded. The same precaution applies to the reference input transformer (Models 213B & C) in those instruments whose phase-sensitive frequency is 400Hz or above. The maximum voltage rating of the reference input transformer is 0.5f (f = Hz).

In the event that signals containing DC are to be injected in the Transformer Mode, a large blocking capacitor should be used externally.

CAUTION

Maximum signal input must not exceed 300V RMS and maximum reference input must not exceed 200V. Higher voltages will break down the input capacitors in the instrument. (See Specifications, Section I.)

3.5 CONTROLS, DISPLAYS, INPUTS. (See Figures 3.1 and 3.2.)

Prior to attempting to operate the instrument, it is advisable that the user familiarize himself with every control, display, and input connection as described below.

3.5.1 POWER AND REFERENCE SELECT SWITCH.

If the pre-specified phase sensitive operating frequency of the voltmeter is 60Hz or 400Hz, the Power Switch will consist of two positions for selecting either External Reference Input or Internal Line Reference Voltage. Power will be indicated by the illumination of the meter face.

3.5.2 REFERENCE ADJUST.

The REFerence ADJust Control is used for adjusting the reference level to read half scale (red line) on the meter.

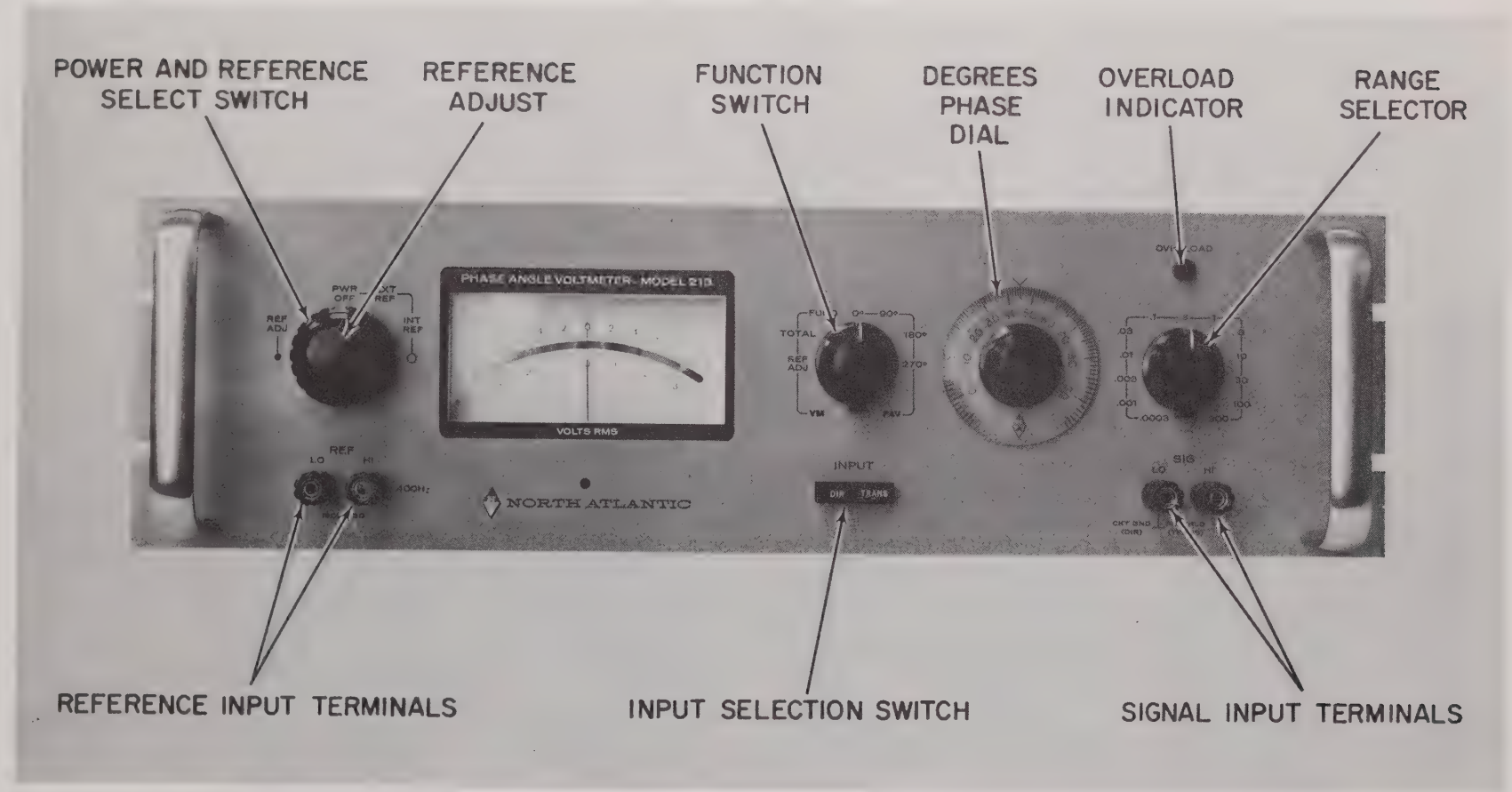


Figure 3.1 Front Panel Controls

Figure 3.2 Back Panel View

This control is used when the FUNCTION switch is in the REFerence ADJust position.

3.5.3 FUNCTION SELECTOR.

The FUNCTION Selector selects the desired mode of operation for the instrument.

In the four PAV (Phase Angle Voltmeter) positions, the instrument is connected so that it may read a voltage E cos θ, where θ is the angle by which the signal vector leads the reference vector. Any of the four quadrants may be selected over which the calibrated degrees phase shifter will operate. Thus, the total angle by which the reference vector is shifted in degrees will be either 0°, 90°, 180°, or 270° plus the reading of the DEGREES Phase Dial.

There are three VM positions. In the TOTAL position, the instrument functions as a standard voltmeter and will read all voltages over a frequency range of 10Hz to 100KHz. In the FUNDamental position, the instrument will read the total vector of the fundamental component of the input signal. (See Figure 4.4 for filter characteristics.)

The FUNCTION Selector must be positioned in the REFerence ADJust position in order to make the proper reference adjustment.

3.5.4 RANGE SELECTOR.

The RANGE Selector is a rotary switch which selects the proper attenuators for the desired full-scale voltage as marked on the front panel.

3.5.5 DEGREES PHASE DIAL.

The DEGREES Phase Dial is calibrated to read the degrees of phase shift introduced by the calibrated phase shifter networks within the particular quadrant selected by the FUNCTION Selector. The DEGREES Phase Dial is calibrated from -6° to +96° in 1° graduations. Mechanical positioning of this dial on its shaft is critical and for this reason, should it be necessary to repair or replace, the procedure under Phase Dial Alignment, paragraph 5.6.3, should be followed.

3.5.6 PHASE ADJUST. (R98 - Located on the rear panel.)

R98 is a screwdriver adjust control used to align the signal and reference channels. Its function is to trim the instrument for minor variations in the frequencies of measured signals from the pre-specified frequency.

3.5.7 OVERLOAD INDICATOR.

The lamp marked OVERLOAD turns on whenever a prescribed signal level is exceeded. This indication warns

of impending amplifier overload and the resultant inaccuracies which will occur when large saturating signals are present. The OVERLOAD Indicator is factory set to turn on when the input exceeds 10 x full scale. (The instrument will function within its specified accuracy up to, and including, a 10 x overload.)

3.5.8 METER.

The meter is a zero center low stiction microammeter calibrated to read the RMS value of a sinewave. For all voltmeter readings, the pointer deflects to the right. For phase-sensitive measurements, the meter deflection may be to the left or right. It has a calibrated zero center 3-0-3 and 10-0-10 with mirror backing for more precise readability.

CAUTION

By its nature, the instrument is required to handle inputs considerably in excess of its fullscale reading. Although a high overload capability has been designed in, discretion should be used to avoid application of signals in a manner which will drive the needle hard against the stops. Therefore, always approach a measurement from the least sensitive position and return to this position before making circuit adjustments. This approach will avoid any damage which may occur to the meter.

3.5.9 INPUT TERMINALS.

These terminal posts are on standard 3/4" spacing and will accommodate banana plugs, wire, or alligator clips. The reference and signal input terminals are designated high and low which indicates polarity with respect to each other (i.e. high is inphase with high; low is inphase with low).

On Model 213C - The signal low terminal is tied to circuit ground in the Direct position. In the transformer position, it is tied to the low side of the primary and the primary shield.

(The Following Applies to Model 213C Only.)

The Model 213C instruments are characterized by the inclusion of a Signal Isolation Transformer with facility for switching the transformer in or out of the circuit. The items listed here exist on the Model 213C front panel only.

INPUT Selector Switch - The INPUT Selector Switch is a push button switch which removes the input transformer from the input circuit in the DIRect position allowing for single-ended, direct-coupled inputs. In the TRANSformer position, floated inputs or differential inputs, as well as single ended, isolation inputs, may be fed into the Signal Channel.

3.6 OPERATION.

Plug the instrument into the proper power source. Turn the POWER Switch ON and allow the instrument to warm up for a short period (3 to 5 minutes) for stable operation.

CAUTION

Before making measurements, review the section on grounding techniques in the Application Notes. (Section VIII)

3.6.1 TO MEASURE VOLTAGE.

Set the RANGE Selector to the appropriate scale and the FUNCTION Selector to the appropriate position. Connect the voltage to be measured to the SIGnal input terminals and read the voltage from either the 0-10 or 0-3 volts scales using the proper scale factor as determined by the RANGE Selector position.

With the FUNCTION Selector in the TOTAL Position, the Voltmeter operates as a standard AC Voltmeter. This reads the total vector voltage at any frequency (within specifications) including all harmonic effects. With the FUNCTION Selector in the FUNDamental position, response of the instrument is determined by filter characteristics.

Notice that with no input to the instrument (terminals not shorted), the meter deflects on the low ranges. This condition is, and represents, a true measurement of stray fields capacitively coupled to the input. Shielding the input will reduce this deflection to a minimum level. Measurements made on high impedance circuits required that special attention be paid to capacitive as well as inductive pickup.

Twisted and/or shielded cable will reduce the effect, though the cable capacity could serve to load the source. Care must be taken, where possible, to insure that ground loops do not exist by virtue of the signal and reference grounds being connected. These loops can result in erroneous readings. (Refer to the Application Notes in Section VIII.)

3.6.2 TO MEASURE PHASE ANGLE.

3.6.2.1 REFERENCE ADJUSTMENT.

A. Switch the FUNCTION Selector to the REFerence ADJust position.

B. Inject the reference signal into the REFerence terminals and adjust the REFerence ADJust Control to cause the meter to read a value as indicated by the red mark on the meter scale. The 'red line' adjustment will vary somewhat as a function of the Phase Dial setting. This is normal and does not indicate malfunction. The 'red line' setting may be made at any setting of the Phase Dial.

3.6.2.2 PRELIMINARY PHASE ADJUSTMENT (R98).

A. This adjustment is factory set and should seldom need to be touched except following servicing and/or component replacement. Using a signal source, equal to full scale on any range greater than 1.0 volts, connect the signal to both SIGnal and REFerence inputs and adjust the reference level in accordance with the preceding paragraph 3.6.2.1.

B. Place the FUNCTION Selector in the 0° position and the DEGREES Phase Dial at 90°, and then FUNCTION Selector in 90° position and the DEGREES Phase Dial at 0°.

If the meter does not read zero for both these tests, use the rear-panel screwdriver adjustment, R98, to provide a zero which is the best compromise for both cases. This control adjusts the phase shift between the signal and reference channels. In general, once this setting is made there is little reason to re-adjust the control.

3.6.2.3 PHASE ANGLE MEASUREMENT-WITH CALIBRATED DEGREES PHASE DIAL.

A. Set FUNCTION Switch to REF. ADJ. position. Connect a reference input to the REFerence terminals, and adjust the reference level by REFerence ADJust Control for red line.

B. Set FUNCTION Switch to FUNDAMENTAL position. Inject the signal to be measured into the Signal Terminals with the RANGE Selector set to a position that will allow a maximum on scale reading.

C. Turn the DEGREES Phase Dial to cause the meter to read a Null on any Phase Sensitive position of the FUNCTION Switch. This step is to provide a coarse measurement of the phase angle.

D. Switch the RANGE Switch to more sensitive positions until the OVERLOAD Light comes on. Then uprange one position so that the OVERLOAD Lamp is off.

E. Adjust the DEGREES Phase Dial more precisely for a Null on the meter. Switch RANGE Switch two positions less sensitive.

F. Switch the FUNCTION Selector to a position (0°, 90°, 180°, 270°) which gives a meter deflection to the right.

G. The phase angle is the sum of the FUNCTION Selector setting of Step F and the Phase Dial setting of Step E.

3.6.2.4 MEASUREMENT OF IN-PHASE (0°) AND QUADRATURE (90°) COMPONENTS.

A. With reference level properly set, place FUNCTION Selector in the 0° position. Set the DEGREES Phase Dial to 0°.

B. The meter now reads the in-phase component of a signal. This is also E cos θ where θ is the angle between the reference and signal.

C. Switch the FUNCTION Selector to 90°. The meter now reads the quadrature component or E sin θ.

In general, one of these components is usually much smaller than the other and for greater accuracy, it is convenient to change the range of the instrument. This can be done until the OVERLOAD Lamp lights, thereby warning of an impending overload condition. This light indicates that the total signal exceeds ten (10) times the full-scale value. Measurements can be made for overloads up to 10 times full scale. Measurements under all these conditions will be most accurate if the zeroing process described in the Application Notes is followed.

3.6.2.5 MEASUREMENTS UNDER MOST SENSITIVE CONDITIONS. Measurements under overloaded (less than 10 times) conditions can be made where it is desired to increase the null capability or to make the small quadrature signal level measurements. As stated previously, the signal levels in the SIGnal Channel may be "10 times the full-scale reading as indicated by the RANGE Switch setting." Under some special conditions, these signals may exceed this 10 times specification by small amounts without overloading the amplifiers in the signal circuits. These

signals, however, should never be increased beyond the level which will cause the OVERLOAD indicator to light.

Accurate measurement of phase angles can be made using the E cos θ or E sin θ characteristic. Voltage measurements are made from the in-phase (0°) or quadrature (90°) component of the fundamental signal and the total vector amplitude as measured in the FUNDAMENTAL Position. The quotient will then be the cosine, or sine, or tangent of the unknown phase angle. Trigonometric tables, slide rule, or graphs included in the appended Application Notes are suitable for converting to degrees. The accuracy achievable using this technique depends upon the procedure, and for that reason, it is suggested the Application Notes be reviewed before using this method.

3.6.3 DIFFERENTIAL MEASUREMENTS AND COMMON MODE REJECTION.

3.6.3.1 DIFFERENTIAL MEASUREMENTS USING AN INPUT TRANSFORMER (VM213C). In making differential measurements using a transformer, there are two sources of error. One is due to capacity from either side of the primary to the high side of the secondary as shown in Figure (A). This can result in an output even if $E_1 = E_2$. Due to coupling into the output impedance of the secondary, this effect is minimized if a secondary shield is used, connected as shown in Figure (B). Note that these capacitors are now capacitors to ground and will cause no coupling to the secondary.

The other source of error is capacity to ground, phase shifting the signal from a source with a finite source impedance as shown in Figure (C). This also can cause an output even if $E_1 = E_2$.

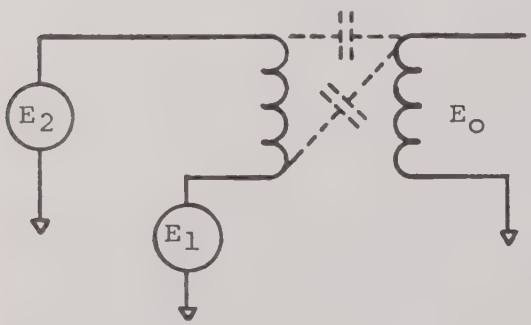


Figure (A)

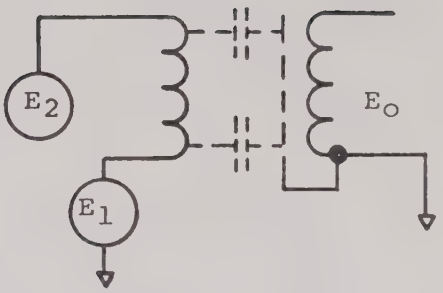


Figure (B)

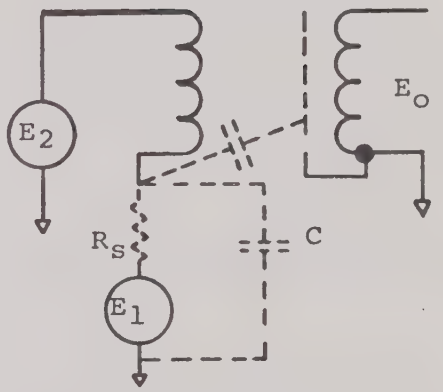


Figure (C)

This effect is minimized if a double shielded wire and a primary shield is used as shown in Figure (D). This will connect the capacity from the inner conductor to the inner shield (C_1) across the transformer which, when nulled, introduces no error. Capacity from the inner to outer shield (C_2), and capacity from the primary shield to secondary shield (C_3) is across E_2. If E_2 has a low source impedance, this will introduce no error.

Therefore, for maximum accuracy in making differential measurements, the lowest impedance source should be connected to the low input terminal.

If it is desired to make differential measurements when high source impedances are present in both input leads, it is sometimes possible to "drive" the primary shield at a voltage equal to E_1 and E_2. This, in effect, places C_3 and C_2 across a third source independent of the voltages being measured. This is shown in Figure (E).

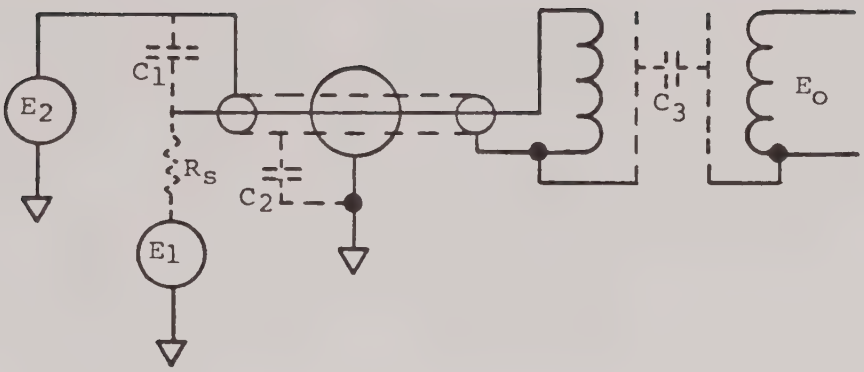


Figure (D)

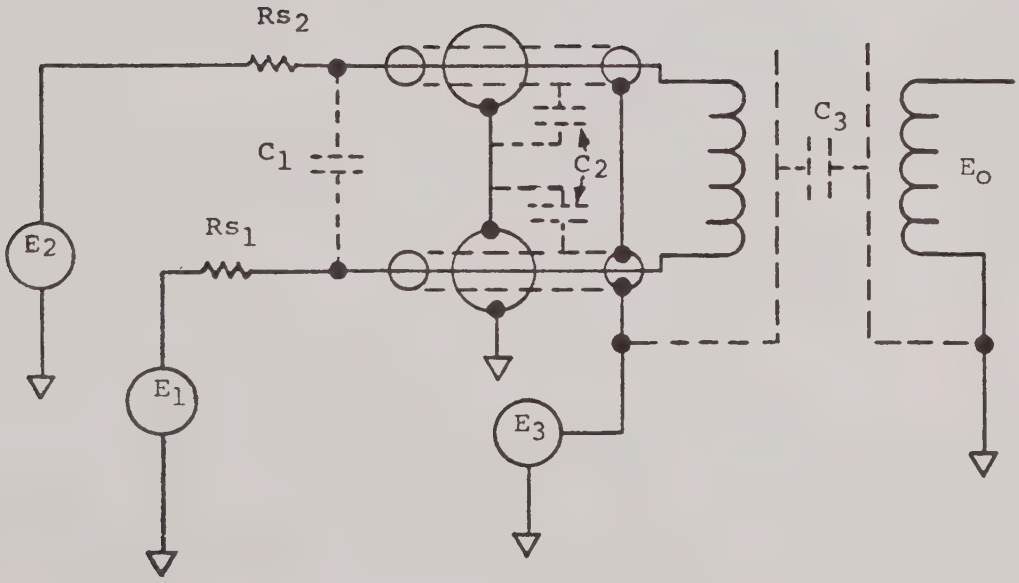


Figure (E)

If it is desired to improve the differential measurement capability over and above that provided by the VM 213C, it is recommended that the user employ an NAI Model T-110 Bridge Null Transformer.

3.6.3.2 COMMON MODE REJECTION (CMR). Common Mode Rejection defines the ability of an instrument to measure a voltage existing between its two input leads (Differential Mode Voltage) in the presence of a voltage to ground common to both input leads (Common Mode Voltage). This type of measurement is frequently encountered when making ungrounded or differential measurements such as the output of AC Bridges.

Common Mode Rejection, expressed in per cent, is defined as:

$$\frac{\text{Differential Output}}{\text{Common Mode Voltage}} \times 100\%$$

It can be measured by shorting the input leads together and applying a Common Mode Voltage to both input terminals, Figure (A), and reading the output of the meter. Should it be desired to measure CMR with a source resistance, use the circuit of Figure (B)

An example of this calculation would be the meter reading 10mV with a CMV of 100V. The CMR would then be

$$\frac{10 \times 10^{-3}}{100} \times 100 = 0.01\%$$

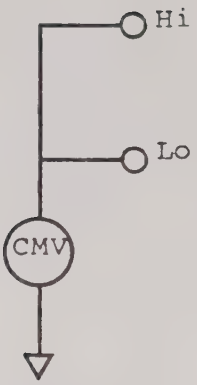


Figure (A)

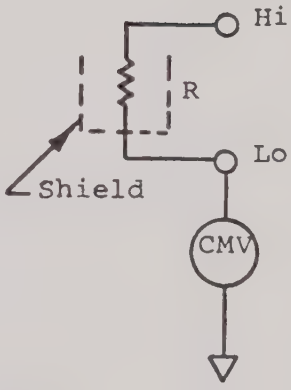


Figure (B)

SECTION IV

THEORY OF OPERATION

4.1 INTRODUCTION.

The block diagram of Figure 4.1 will serve to illustrate the principles of operation of the Phase Angle Voltmeter. The Phase Angle Voltmeter is a multi-function instrument, and the following will describe each of these functions.

4.2 GENERAL THEORY.

4.2.1 TOTAL AND FUNDAMENTAL VOLTMETER.

When operating as a Total and Fundamental voltmeter, the instrument uses only the signal channel circuitry. The signal amplifier, in conjunction with the range attenuator, functions as a conventional AC Electronic Voltmeter. The signals applied to the input are amplified and fed to the full-wave rectifier circuit and indicated on the meter, which is calibrated in RMS. (See Table 1, page 4.5 for errors due to harmonics.)

As a Fundamental Voltmeter, a harmonic filter is switched into the circuit and the meter will read only those frequencies within the pass band of the filter. See Figure 4.4 for filter characteristics.

4.2.2 PHASE ANGLE VOLTMETER.

As a Phase Angle Voltmeter, the reference channel is activated and operates in conjunction with the Fundamental mode circuitry of the signal channel. The reference signal is phase shifted by the calibrated reference phase bridge circuitry, amplified, and then filtered. The reference channel output serves to gate the demodulator portion of the meter circuit. The relationship of this gating voltage to the signal being measured will determine the magnitude and the polarity indicated on the meter.

For those signals which are in-phase, a signal of maximum amplitude will be indicated and for those signals which are 90° out-of-phase (Quadrature), a minimum signal will be read. Where the instrument is being used to read quadrature signals, these signals may exceed the indicated range by up to 10 times without overloading the signal amplifier circuits. This capability provides a means for much more accurate measurements of quadrature voltages and computation of phase angles.

4.3 DETAILED THEORY.

4.3.1 SIGNAL INPUT ATTENUATOR.

The signal amplifiers of the Model 213 always operate with the same basic sensitivity (300μV). This requires attenuators for reducing higher level voltages to this range. The input attenuator actually consists of two separate voltage divider networks. The first provides a 1000:1 reduction for voltages .3 volts and above. The second provides seven attenuator ranges from 1:1 to 1000:1. This latter attenuator provides attenuation for signals up to and including 100mV and is added to the attenuation of the 1000:1 divider for signals between 1 volt and 300 volts.

At low frequencies, the 1000:1 attenuator ratio is determined solely by the resistors employed. At higher frequencies, capacitive compensation is necessary to compensate for circuit strays. This converts the attenuator to a capacitive divider at high frequencies. The crossover from resistive to capacitive attenuation occurs at approximately 600Hz. This attenuator when properly adjusted not only provides proper attenuation at both high and low frequencies, but also has essentially zero phase shift over the rated frequency range. See Adjustment Procedure, page 5.8, for proper alignment.

4.4 AMPLIFIERS.

Signal Isolation Amplifier - The signal isolation amplifier provides a high input impedance to the input signal and a low output impedance to the range attenuator. It has a gain of 3.2 and provides a wide band frequency response with minimal phase shift and low noise. R25, C17, R33, and CR7, 8, 9, and 10 provide overload protection for the amplifier and will allow 300V RMS to be applied indefinitely to the input with the RANGE switch on the 300μV range.

Amplifiers - The amplifiers (Z2, Z3, Z4, Z6, and Z7) that are used in this voltmeter are dual operational amplifiers. They are all used in a high feedback gain configuration to assure maximum stability with time and temperature.

Z6 A and B are the Fundamental and Total mode amplifiers. Each amplifier has a gain adjust pot for adjusting

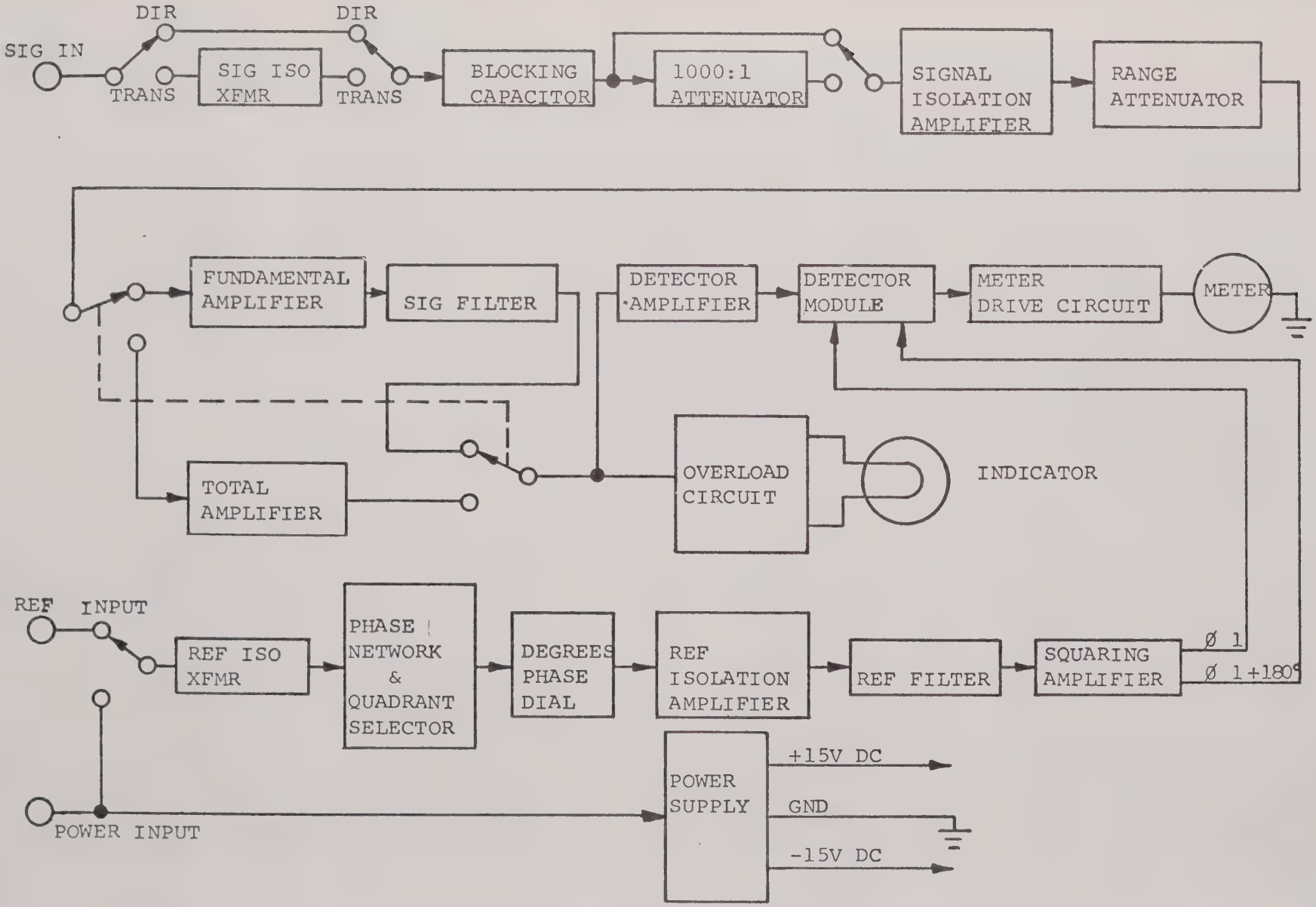


Figure 4.1 Phase Angle Voltmeter Model 213, Block Diagram

the meter to full scale. Each amplifier is in a non-inverting configuration with a nominal gain of 150.

Z7 and its associated circuitry is the signal channel filter. This low pass active filter provides harmonic rejection in the Fundamental and Phase Sensitive modes. Typical characteristics are shown in Figure 4.4.

Z3A is the reference isolation amplifier which provides a non-inverting unity gain and high input impedance to prevent loading of the phase pot, R4.

Z3B provides a gain of 35 for the reference signal.

Z2 A and B is the reference channel filter. Its components and circuitry are exactly the same as the signal channel filter.

Z4 A and B is the reference squaring amplifier. This amplifier provides two 30V P-P square waves which are 180° out of phase with each other and are used to gate the phase sensitive detector

Detector and Meter Drive Amplifiers - Z5 and Z9 are single stage operational amplifiers which remove the effects of nonlinear switching elements in the Detector Module. Its configuration also provides full-wave switching operation.

4.5 DETECTOR CIRCUIT.

Detector Module Z8 - The detector is a proprietary module which functions in the Total and Fundamental modes as a full-wave rectifier averaging detector, and in the phase angle modes functions as a phase sensitive detector.

The detector's phase sensitive operation can be likened to that of a set of commutating switches. The reference signal causes signal current to flow through the meter in alternate directions in each half cycle of the reference signal. See Figure 4.2. When the reference and signal are in-phase (Figure 4.2A), the average value of this current will be maximum and the meter will read a maximum voltage. When the signals are 90° apart (Figure 4.2B), the average will be zero and no reading will resul: The equation governing this is:

$$I_{Meter\ (avg)} = K E \cos\theta$$

where K = proportionality constant
E = RMS of signal
θ = angle between signal and reference

Detector saturation effects will limit this characteristic equation to the design levels for the instrument. Under special conditions, such as are described in the appended Application Notes, the reference level is increased to improve accuracy for high signal levels. Measurements at the quadrature null point ($\theta = 90°$) are relatively unaffected by saturation.

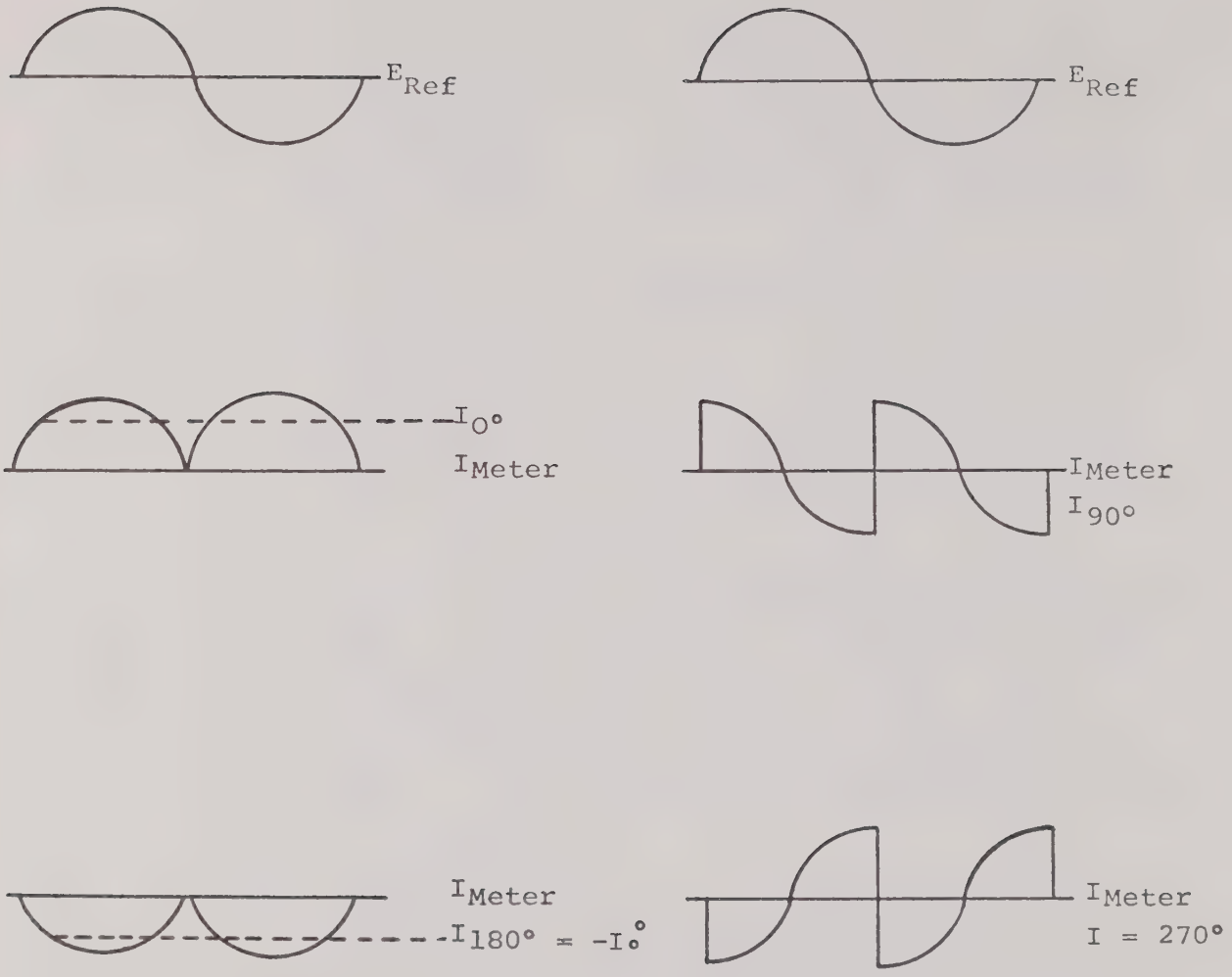
The response of the Detector is limited to signals at the reference frequency as well as to odd-order harmonics. Response for this type detector to odd-order harmonics will never be greater (usually less, depending upon phase angle) than the fundamental response multiplied by a factor 1/n where n is the order of the harmonic. Where a signal channel filter is used, there is, of course, essentially no response to harmonics in the signals.

All other frequencies are rejected except for signals very near to the reference frequency and its odd harmonics. Here, the meter movement will oscillate between 0 degrees in-phase and 180 degrees out-of-phase and at a frequency proportional to the difference between the input frequency and the fundamental or third harmonic of the reference signal. Response of this nature is limited to frequency differences of about 5Hz (meter pass band).

The effect of reference harmonics is much less important than that of signal harmonics because the harmonic content can never do more than shift the point at which the current starts to flow. Expressed otherwise, there is an equivalent error in degrees which results from harmonics in the reference channel. For measurements using the DEGREES Phase Dial, the error can be removed by trimming. For measurements using E cos θ characteristic, the effect is small because the meter reading as a function of current integrated over an entire cycle and the small error produced by distortion has a correspondingly small effect on the total current.

When used as a conventional Total or Fundamental voltmeter, the Detector is switched to a full-wave rectifier configuration. Operation is identical to that of a full-wave bridge power supply in which the meter movement acts as the load.

Effects of Distortion - The current through the meter in the latter circuit is proportional to the average value of the voltage waveform applied. Calibration of the meter in RMS is based on a ratio between the average and effective values of a true sinusoidal voltage. Deviation from a true sinewave may cause errors in the meter



IN PHASE (0°/180°)
(A)

QUADRATURE (90°/270°)
(B)

Figure 4.2 Phase Detector Waveforms

indication. Table I lists the range of possible errors due to the second and third harmonic distortion

Table I. Errors Due to Harmonics in a Typical Average Detector

Harmonic Order	Harmonic Content	Error
2nd	10%	Nil
2nd	20%	0 to +2%
2nd	50%	0 to +10%
3rd	10%	-4% to +4%
3rd	20%	-6% to +8%
3rd	50%	-10% to +16%

Overload Circuit - The OVERLOAD Detector Circuit is designed to operate as a switch. When the signal level exceeds a level of approximately 12 times full scale, the circuit will switch turning on the OVERLOAD indicator. The signal amplifiers will operate up to and including 10 times overload. The indicator is set to light above this level, and ordinarily measurements may not be made as long as the indicator is lit.

4.6 PHASE BRIDGE NETWORK.

The Phase Bridge Network is required to generate the precision phase shifts in the reference channel. These networks are designed for specific frequencies as required by the individual user. An output of 0°, 90°, 180°, and 270° is provided and is selected by the FUNCTION switch. Angles in any quadrant are determined by connecting the DEGREES Phase Dial potentiometer to any two adjacent points through the FUNCTION switch. This provides a phase shift capability of 0° to 360° as determined by the FUNCTION switch setting plus the DEGREES Phase Dial (phase potentiometer) setting. (See Fig. 4.3)

The voltage E-R4 appears across the DEGREES Phase Dial potentiometer R4 between the taps, terminals 1 and 5. When E/0° is set equal to E/90°, the electrical angle E/ϕ is a non-linear function of the potentiometer shaft angle. This is compensated by a non-linear DEGREES Phase Dial. This function is described by the equation shown.

The 90° angular rotation is shifted to any quadrant by the four corners of the bridge being rotated to cause the desired quadrant voltage to appear across the DEGREES Phase Dial potentiometer. This is performed by the FUNCTION switch.

4.7 POWER SUPPLY.

The power supply can be operated at 45Hz-440Hz, 115V/125V. An internal switch is provided for operation at 230V/250V. The AC voltage is full-wave rectified, filtered, and applied to Q1 and Q2 which provide a constant +15V and -15V DC output. CR5 and CR6 are 16V Zener diodes.

4.8 FILTERS.

The filters used are fifth order, 0.5DB, Chebyschev, low pass active filters which are operated in a restricted portion of the pass band. This is to maintain the amplitude gradient over this band within the instrument's specifications and to restrict the phase variation. Figure 4.4 is a typical filter response. F_m designates the geometric mean frequency of the usable band. The upper-frequency limit is determined by the amplitude vs. frequency characteristic. Lower-frequency limit is determined by the amount of rejection of the third harmonic of this frequency.

Many resistor and capacitor components in the filter are changed for different frequencies. Refer to the Filter Component Table on the schematic Fig. 5.6 for these changes.

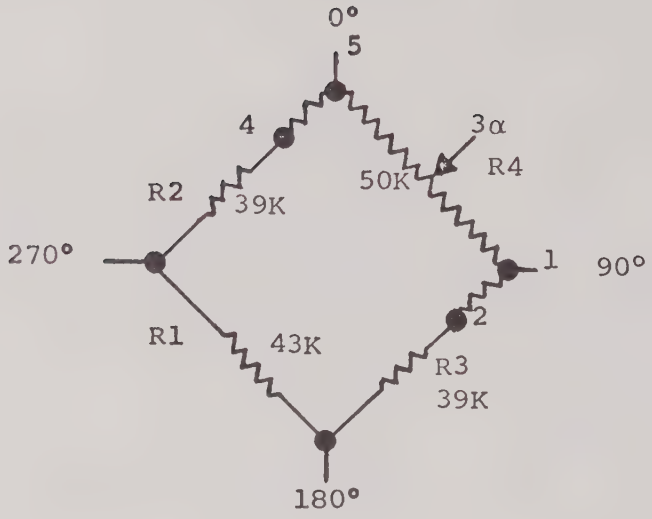
Note

When making phase-sensitive measurements, the detector circuit inherently has a high second harmonic rejection (approx. 55DB) and 10DB additional rejection of the third harmonic. This additional harmonic rejection is individually added to the filter rejection when operating in any phase-sensitive mode.

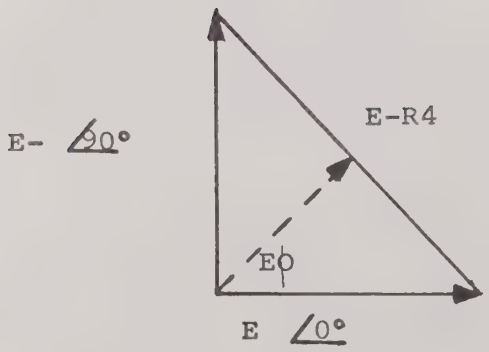
4.9 INPUT ISOLATION TRANSFORMERS.

Both Models 213B and 213C have a Reference Isolation Transformer in their Reference Input. This will allow a common reference signal to be connected to the instrument without creating a ground loop.

The Model 213C is characterized by the inclusion of a SIGnal Isolation Transformer in its SIGnal input, as well as containing the above mentioned REFerence Isolation Transformer. The INPUT DIR/TRANS switch provides a means of switching this SIGnal Isolation Transformer in and out of the SIGnal input as desired. This transformer may be used for making single-ended, as well as differential, measurements.



PHASE SHIFT BRIDGE



$E\angle 0° = E\angle 90°$

$\theta = \theta \text{ Max } \frac{\text{Tan } \phi}{1 + \text{Tan } \phi}$

ϕ = Electrical Phase Angle

θ = R4 Shaft Angle

Frequency in Hz

Figure 4.3 Voltage Vector at Phase Potentiometer

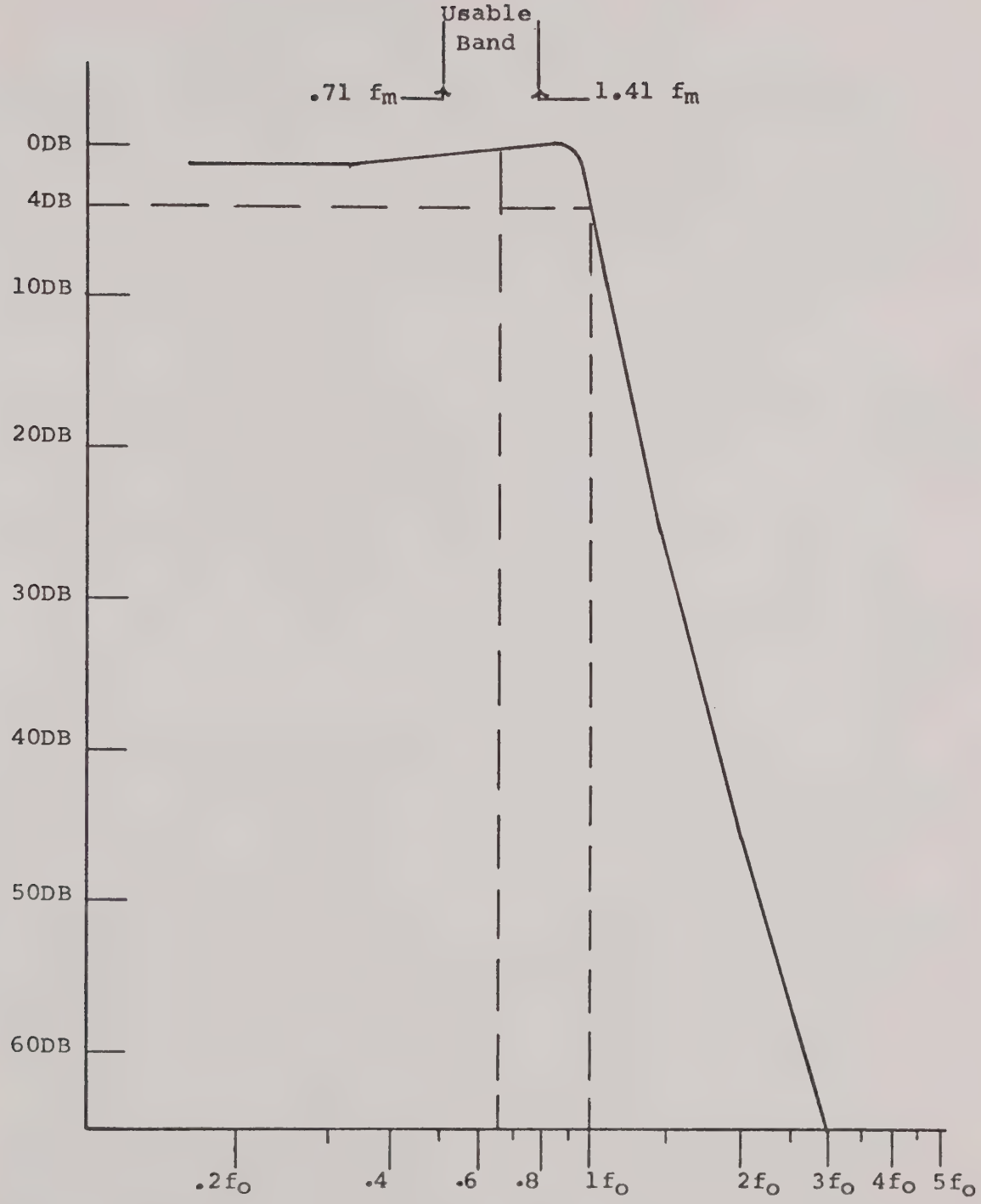


Figure 4.4 Typical Filter Characteristics

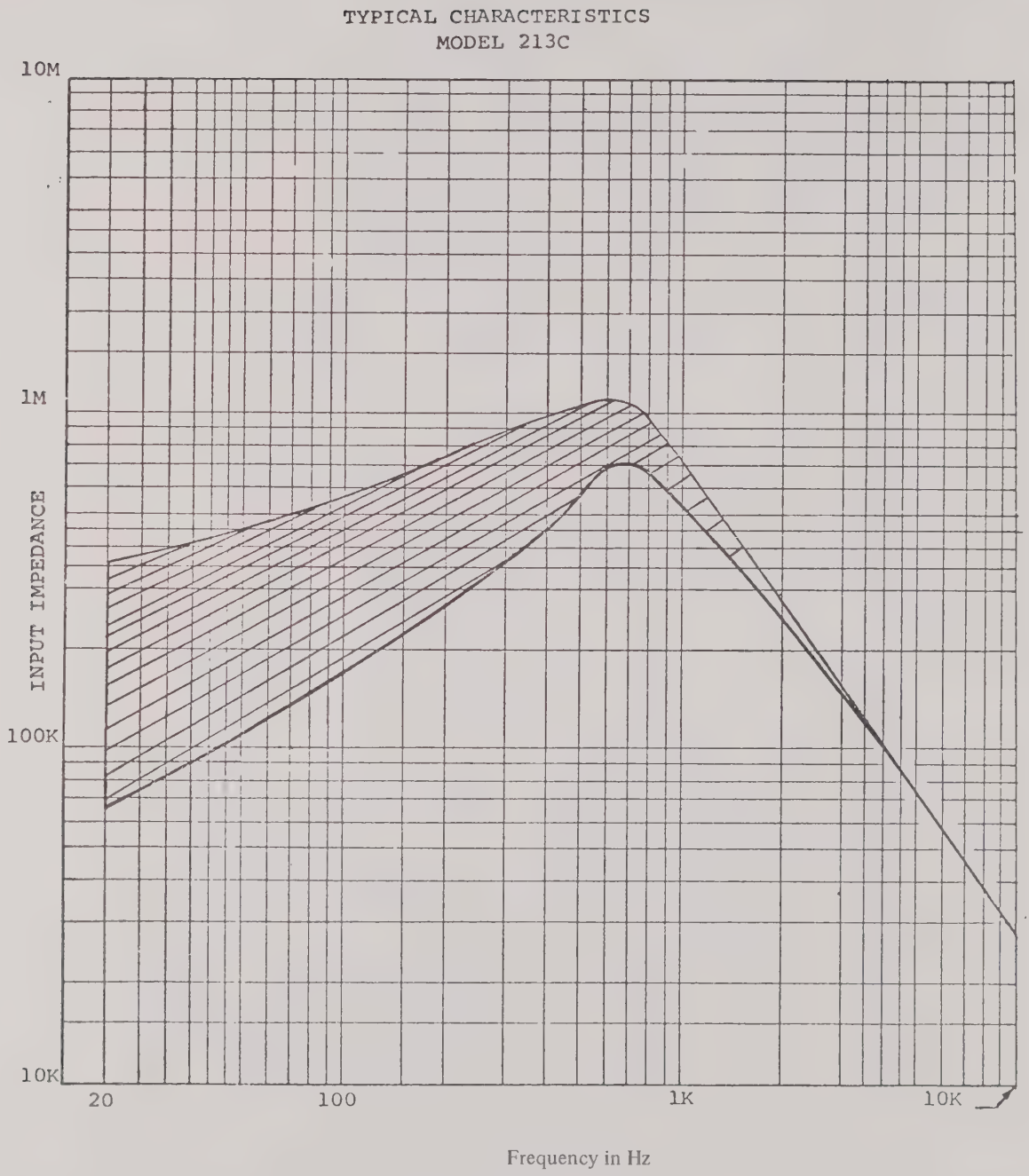


Figure 4.5 Input Impedance vs. Frequency (Transformer Mode)

SECTION V

MAINTENANCE

CAUTION

HIGH VOLTAGE EXISTS AT SEVERAL POINTS IN THE INSTRUMENT. NORMAL PRECAUTIONS CONSISTENT WITH GOOD PRACTICE SHOULD BE TAKEN TO REDUCE SHOCK HAZARD.

A potential shock hazard exists when ungrounded power source or ungrounded case operation is employed. Persons operating the instrument should be made aware of and take precautions against this condition.

North Atlantic Industries, Inc. cannot be held responsible for damage to persons or property in the process of or as a result of maintenance, calibration, or setting up of the instrument.

5.1 INTRODUCTION.

The following section contains instructions for the general maintenance of the Phase Angle Voltmeter. Performance testing, alignment procedures, and troubleshooting are described here.

5.2 COVER REMOVAL.

In order to service, it is necessary to remove the top cover of the instrument via the removal of five screws. For additional troubleshooting and maintenance, it may become necessary to remove the bottom cover of the instrument which may easily be accomplished by removing five screws.

5.3 REPLACEMENT OF PRINTED CIRCUIT CHASSIS COMPONENTS.

There are a number of components which are mounted directly to the printed circuit chassis, all of which are easily accessible. In the event that any of these must be replaced, normal precautions consistent with good manufacturing practice should be followed.

There are also a number of components which are mounted to switch assemblies. In the even there is a failure in any of these components, it is recommended that extreme care be exercised in the removal of these components so as to not damage the switch wafer.

5.4 REPLACEMENT OF FUSE.

A power fuse is mounted on the rear panel of the unit and may easily be replaced by removing the fuseholder cap. This fuse will normally be a .5 amp fuse, type 3AG, for 115V operation. For those instruments which operate with 230V power source, this fuse should be a .25 amp, type 3AG.

5.5 PERFORMANCE EVALUATION.

It is the purpose of this procedure to assist a qualified technician in the recalibration of the Model 213 Phase Angle Voltmeter. Under normal circumstances, this instrument, due to the use of solid-state circuitry, should require a minimum of service and recalibration.

The Test Procedure portion of Section V may be used for incoming acceptance test or for periodic calibration checks. It is recommended that the initial periodic check be made after three months and future checks be extended to six months or yearly checks.

The Alignment Procedure within Section V may be used for recalibration in the event there is failure which requires the replacement of any component in the instrument.

5.5.1 EQUIPMENT REQUIRED.

Refer to table II for list of equipment required.

5.5.2 PROCEDURE.

5.5.2.1 PRELIMINARY CHECKS.

A. Before turning on equipment, check mechanical zero of the meter and re-zero if necessary.

Table II. Equipment Required

Test Equipment	Capability/Type	Application
Variable Voltage Source	Frequency Accuracy ±5% Voltage 0 to 300V Frequency Range 10Hz to 100KHz (e.g. Elin AD0102)	Voltage and Frequency Response Calibration
Scale Voltmeter, Monitor	Accuracy: ±0.5% Calibrated full Scale 400Hz*	Voltage Calibration
Voltmeter, Monitor	Flat Freq. Response: ±0.25%, 10Hz to 100KHz (e.g. Hewlett-Packard Model 738BR)	Frequency Response
AC Ratio Box (2)	NAI Model RB-503	Voltage Calibration
Phase Generator**	NAI Model 350	Phase Calibration
High Impedance Ohmmeter	Hewlett-Packard Model 412	Phase Dial Alignment
Oscilloscope	Tektronix Model 422	Troubleshooting

*This frequency is the pre-specified phase-sensitive operating frequency. Since 400Hz is a common frequency, it is used throughout this section.

**See Paragraph 5.5.2.7 for less convenient methods of Phase Angle generation.

B. Ground Isolation Check (instrument turned off):

1. Check resistance between chassis ground and circuit ground at the signal input terminals. (Link must be removed.) This should read open.

C. Noise Check (instrument on, chassis connected to house ground, ground link in place):

1. Short SIGnal input terminals, apply a 100V REFerence signal, and adjust the reference level to red-line value.

2. Reading on the meter should not exceed 15μV on any range in the TOTAL and FUNDamental Modes. In the PAV (Phase Sensitive) Modes, the meter indication should be less than 2μV.

5.5.2.2 VOLTAGE CHECK.

FUNCTION Switch - TOTAL
INPUT TRANSformer/DIRect Switch - DIRect
(Model 213C only)

A. Connect the instrument as shown in Figure 5.4A, and adjust the Variable Voltage Source amplitude to 100V. Adjust reference level to red-line value.

B. Apply a voltage to the SIGnal input terminals corresponding to the full-scale indication at each position of the RANGE Switch by setting the AC Ratio Box as required. The accuracy of the input voltage should be ±0.5%. The Model 213 should indicate these values ±2% of full scale.

1. Set RANGE Switch to 300μV.

2. Apply a 300μV ±0.5%, 400Hz* to the SIGnal input terminals.

3. Meter should now read 300μV ±2%.

4. Set RANGE Switch to 1mV.

5. Apply a 1mV, ±0.5%, 400Hz* to the SIGnal input terminals.

6. Meter should now read 1mV ±2%.

7. Set RANGE Switch to 3mV.

8. Apply a 3mV ±0.5%, 400Hz* to the SIGnal input terminals.

9. Meter should now read 3mV ±2%.

10. Set RANGE Switch to 10mV.

11. Apply a 10mV ±0.5%, 400Hz* to the SIGnal input terminals.

12. Meter should now read 10mV ±2%.

13. Set RANGE Switch to 30mV

14. Apply a 30mV ±0.5%, 400Hz* to the SIGnal input terminals.

15. Meter should now read 30mV ±2%.

16. Set RANGE Switch to 100mV.

17. Apply a 100mV ±0.5%, 400Hz* to the SIGnal input terminals.

18. Meter should now read 100mV ±2%

19. Set RANGE Switch to 300mV.

20. Apply a 300mV ±0.5%, 400Hz* to the SIGnal input terminals.

21. Meter should now read 300mV ±2%

22. Set RANGE Switch to 1V.

23. Apply a 1V ±0.5%, 400Hz* to the SIGnal input terminals.

24. Meter should now read 1V ±2%.

25. Set RANGE Switch to 3V.

26. Apply a 3V, ±0.5%, 400Hz* to the SIGnal input terminals.

27. Meter should now read 3V ±2%.

28. Set RANGE Switch to 10V.

29. Apply a 10V ±0.5%, 400Hz* to the SIGnal input terminals.

30. Meter should now read 10V ±2%.

31. Set RANGE Switch to 30V ±2%.

*Use the pre-specified phase-sensitive operating frequency.

32. Apply a 30V ±0.5%, 400Hz* to the SIGnal input terminals.

33. Meter should now read 30V ±2%.

34. Set RANGE Switch to 100V.

35. Apply a 100V ±0.5%, 400Hz* to the SIGnal input terminals.

36. Meter should now read 100V ±2%.

37. Set RANGE Switch to 300V.

38. Apply a 300V ±0.5%, 400Hz* to the SIGnal input terminals.

39. Meter should now read 300V ±2%.

C. Switch the FUNCTION Switch to FUNDamental and repeat B.

D. (Model 213C instruments only.) Switch the INPUT TRANSformer/DIRect Switch to TRANSformer with the FUNCTION Switch in FUNDamental position. Repeat Step B.

E. Linearity Check - Inject a full-scale signal into the SIGnal input terminals. Switch the FUNCTION Switch to FUNDamental. Change input SIGnal down scale in discrete steps. Meter should indicate corresponding levels as follows (±2%)

Range	Input	Meter X Full Scale
1V	1.0V	1.0
1V	.8V	.8
1V	.6V	.6
1V	.4V	.4
1V	.2V	.2
1V	.1V	.1

5.5.2.3 FREQUENCY RESPONSE. (See Figure 5.4D.)

A. Set FUNCTION Switch to the TOTAL Mode. Set RANGE Switch to 0.1V. Set INPUT TRANSformer/DIRect Switch to DIRect (Model C only).

B. Using the Variable Voltage Source, inject a signal equal to 0.09V at 400Hz*. Monitor this input voltage with the Monitor Voltmeter. (It is necessary that the frequency response be flat to within 0.5% over a range of 10Hz to 100KHz.)

C. Sweep the frequency of the Variable Voltage Source from 10Hz to 100KHz and maintain a constant amplitude output. Meter should indicate a 0.09V ±2% from 20Hz to 50KHz, and 0.09V ±5% from 10Hz to 100KHz.

D. Switch RANGE Switch to 1.0V and set Variable Voltage Source to 0.9V and repeat Step C.

Note

Meter should read 0.9V instead of 0.09V.

5.5.2.4 SIGNAL AND REFERENCE CHANNEL PHASE ALIGNMENT.

A. Using the test circuit shown in Figure 5.4B, set the Variable Voltage Source to 400Hz*, and adjust the amplitude to nominally 100V.

B. Turn FUNCTION Switch to REFerence ADJust and adjust the reference level for red-line value on the meter scale.

C. Set FUNCTION Switch to FUNDamental, RANGE Switch to 0.010V, and connect 90° RC network (or Mod 350) to SIGnal input terminals. Adjust the Variable Voltage Source slightly until a full-scale reading (0.01V) is obtained on Phase Angle Voltmeter.

D. Set DEGREES Phase Dial to 0°. Set FUNCTION Switch to 0°. Set RANGE Switch to 0.001V (approx. 10 times overload).

E. Adjust PHASE ADJust Control R98 (rear-panel control) for zero reading on meter.

Note

Signal and reference Channel are now phase aligned. The 0° FUNCTION and 0° DEGREES Phase Dial positions are now calibrated.

5.5.2.5 PHASE CHECK. (For methods of generating phase angles, see Paragraph 5.5.2.7.) The following checks should be made at 400Hz* using Figure 5.4C.

A. Using a 10 volt level into the REFerence input terminals, set FUNCTION Switch to REFerence ADJust

*Use the pre-specified phase-sensitive operating frequency.

position and set REFerence ADJust Control to cause the meter to read red line (red line is marked at half scale on the meter).

B. Set FUNCTION Switch to 90°. Set DEGREES Phase Dial to 0°. Set RANGE Switch to 0.001V.

C. Inject the 0.010 V (10 times overload 0° signal from the Phase Generator into the SIGnal input terminals.

D. Adjust DEGREES Phase Dial to cause the meter to read a null (0). The indicated angle should be ±1° of the input angle (i.e. - with a 0° input, the DEGREES Phase Dial should read between -1° and +1°).

E. Repeat Steps C and D in 10° increments to 90°. The DEGREES Phase Dial readings should all be within ±1° of the input angle.

5.5.2.6 OVERLOAD CHECK.

A. Using the test connections of Paragraph 5.5.2.5A, set the DEGREES Phase Dial to 0°, the FUNCTION Switch to 90°, and the RANGE Switch to 0.1V.

B. Inject a 0° signal into the SIGnal input terminals at approximately 1.0V level (10 X overload). Meter will indicate zero.

C. Gradually increase the input signal until overload light comes on. This should occur at approximately 12 X overload (1.2V).

5.5.2.7 PHASE ANGLE GENERATION. The test procedure requires that phase angles other than 90° or 0° be used for some checks. The Model 350 Phase Generator is suitable for this purpose.

Model 350 Phase Generator (See Figure 5.1.)

The Model 350 Phase Generator is a completely passive phase shifter.

It operates on the well-know principle of a resolver-type phase shifter. The reference signal is phase shifted through a precision 90° RC network and this signal E/90° is applied to a trigonometric (sine) transformer divider. The reference signal E/0° is applied to another trigonometric (cosine) divider, but only after being attenuated to the same magnitude as E/90°. The outputs of the two dividers are then combined in a summing transformer which also provides output isolation. The dividers are tapped to permit selection of all trigonometric voltages between E/0° and E/90°, such that the summed output is E/a where a is the setting of the front panel dials. A convenient four-position quadrant switch permits generation of any angle from 0° to 360°.

Model 351 Phase Calibrator

The Model 351 Phase Calibrator is used where maximum precision is desired in the presence of harmonics. It is used to set the magnitudes E/0° and E/90° to be equal. In addition, the Phase Calibrator contains an amplifier which raises the Model 350 output from 30mV to 10V. Provision is also made to permit use of an external amplifier where higher voltage levels are desired.

Provision is made to remove the nominal test system phase shift through the use of ±4° angle offset controls on the Model 350 Phase Generator.

The Model 350 Phase Generator may be used with or without the Model 351 Phase Calibrator. All interconnections between the two chassis are made by means of a cable provided with the Model 351 Phase Calibrator.

If this equipment is not available, it is suggested that the following methods be used:

RC Passive Phase Shifter (See Figure 5.2.)

Precise phase angles can be generated using the circuit configuration shown. These networks are very useful and are simple to construct. They do require, however, accurate measurement of component values. They may be constructed with the aid of the design equations shown in Figure 5.2. The components should be high quality, stable devices; such as mica, or polystyrene capacitors, and metal film or deposited carbon resistors.

Ratio Box Phase Shifter (See Figure 5.3.)

This circuit is somewhat less complicated than the previous circuits in that it required only a precise 0° and 90° signal be generated by use of passive networks, but it does require a Model RB-503 Ratio Box. Alternate Ratio Boxes must be accurate at the operating frequency. The components again must be high quality and drift free. It may be seen that any angle between 0° and 90° can be selected depending on the setting of the Ratio Box. It should be noted, however, that the amplitude of the 0° and 90° signal should be set equal to each other. The output amplited will vary through a minimum of 0.707 of the 0° and 90° signal at 45° (Ratio Box setting of 0.5).

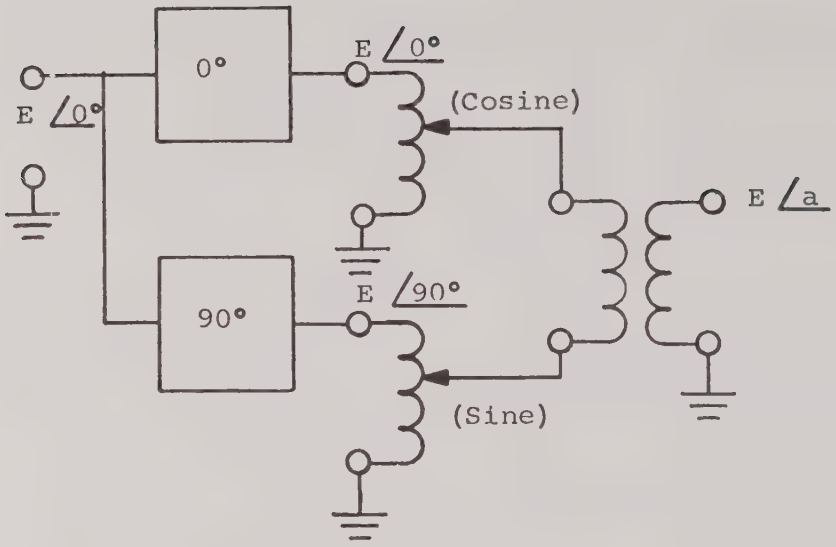
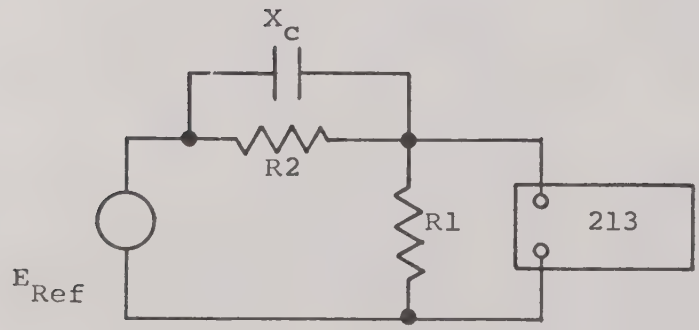


Figure 5.1 Model 350 Phase Generator, Functional Schematic

$$\text{Attenuation} = \frac{R_1}{|Z|} \qquad \text{Providing } R_1 \mathbin{//} |Z|$$

$$\text{Phase Shift} = \text{Tan}^{-1}\ \frac{R_2}{X_C}$$



$$Z = \frac{R_2}{1 + j\ \frac{R_2}{X_C}}$$

$$Z = \frac{R_2 X_C \sqrt{X_C^2 + R_2^2}}{X_C^2 + R_2^2}$$

Figure 5.2 RC Passive Phase Shifter

Phase network component values and Ratio Box settings are determined by the equation shown in Figure 5.3.

5.6 ALIGNMENT PROCEDURE.

5.6.1 PRELIMINARY CHECKS.

A. Before turning on equipment, check mechanical zero of the meter and rezero if necessary.

5.6.1.1 GROUND ISOLATION CHECK.

A. Check resistance between chassis ground and circuit ground at the signal input terminals (link must be removed). This should read Open. Replace link.

5.6.1.2 POWER SUPPLY CHECK. Set RANGE Switch to 300V, turn instrument on, and measure the following with respect to ground:

A. Using the circuit schematic, Figure 5.6, check +15V at TP8, -15V at TP7. Each should read 15.4V ± .8V.

B. Check ripple with an A.C. VTMV. Should not exceed the following:

+15V 3mV RMS
-15V 3mV RMS

5.6.1.3 DC METER OFFSET.

A. Set SIGNAL INPUT Switch to Direct position.

B. Short Signal Input terminal to Ground.

C. Set FUNCTION Switch to REFerence ADJust position.

D. Set REFERENCE Switch to EXT position. (60Hz - 400Hz units only.)

E. Feed in 10V 400Hz* to Reference Input Terminals.

F. Set REFerence ADJust Knob for a red line reading on meter.

G. Set FUNCTION Switch to 0° position.

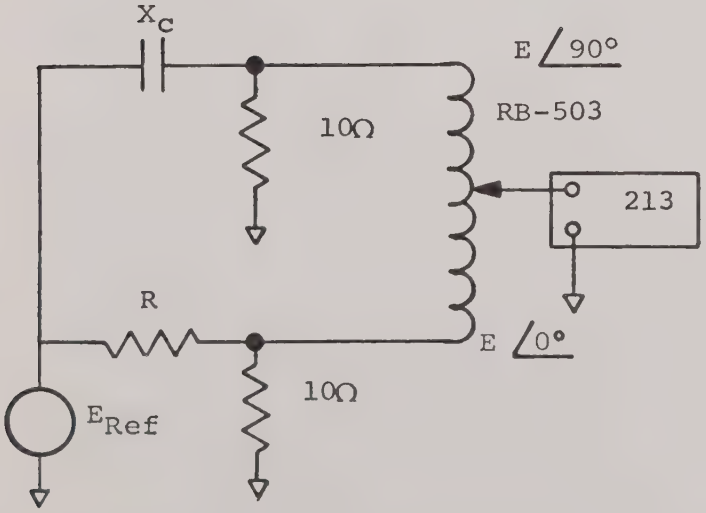
H. Set RANGE Switch to 0.1V position.

I. Connect an AC Voltmeter to TP12 and adjust R111 for a minimum AC reading.

J. Adjust R95 for zero reading on the meter.

K. Make sure that the meter reads the same (zero) in Fundamental and 0° positions of the FUNCTION Switch.

*Use the pre-specified phase sensitive operating frequency.



$\frac{X_C}{10} \gg 1000$

$R = X_C$

$E\angle 0°$ and $E\angle 90°$ must be set equal within 1/4%

Ratio Box setting =

$\frac{1}{1 + \text{ctn } \theta}$ where θ is desired phase shift

Figure 5.3 Ratio Box Phase Shifter

5.6.1.4 NOISE CHECK.

A. Short SIGnal input terminals; apply a 100V REFerence signal.

B. Reading on the meter should not exceed 15μV on any range in the TOTAL and FUNDamental modes. In the PAV (Phase Sensitive) Modes, the meter indication should be less than 2μV.

5.6.2 VOLTAGE ALIGNMENT.

Connect as in Figure 5.4A and refer to Figure 5.5 for location of printed circuit chassis trim controls. Turn instrument on, and allow a 15-minute warm up.

The following adjustments are for the purpose of calibrating the basic voltage gain of the instrument in the TOTAL and FUNDamental Modes. It also incorporates the "broadband" adjustment of the 1000:1 standard input attenuator.

(Set INPUT DIRect/TRANSformer Switch to DIRect in Model 213C instrument.)

A. FUNDamental ADJustment

1. Set Variable Voltage Source to 100V as measured on the Monitor Voltmeter at 400Hz*.

2. Set RANGE Switch to 0.1V, FUNCTION Switch to FUNDamental.

3. Set Ratio Box to .001000 (0.1V).

4. Adjust FUNDamental ADJust Potentiometer (R47) for full-scale indication on the meter.

B. TOTAL ADJustment (Same as in Paragraph A)

1. Set FUNCTION Switch to TOTAL Mode.

2. Adjust TOTAL Potentiometer (R53) for a full-scale reading on the meter.

(In Model 213C instruments, set INPUT DIRect/TRANSformer Switch to TRANSformer and recheck Steps A and B.)

*Use the pre-specified phase-sensitive operating frequency.

C. 1000:1 Input Attenuator Adjustment

(For Model 213C Instruments, set INPUT DIRect/TRANSformer Switch to DIRect.)

This attenuator must operate over the entire frequency range of the instrument in the TOTAL Mode. Therefore, it must be adjusted for a "flat" amplitude characteristic and a minimum phase shift over this range.

1. FOR INSTRUMENTS WHICH OPERATE AT A PHASE SENSITIVE FREQUENCY BETWEEN 160Hz AND 1KHz, CONNECT INSTRUMENTS AS SHOWN IN FIGURE 5.4A.

a. Set Variable Voltage Source for precisely 10V as measured on the Monitor Voltmeter at 400Hz*.

b. Set Ratio Box to .001000 (0.01V).

c. Set FUNCTION Switch to REFerence ADJust. Set REFerence ADJust Control for the red-line mark on the meter.

d. Set RANGE Switch to 0.001V, FUNCTION Switch to 90°.

e. Rotate DEGREES Phase Dial until meter reads precisely zero.

f. Set RANGE Switch to 10V position, and FUNCTION Switch to FUNDamental.

g. Set Ratio Box for 1.000000 (10V).

h. Adjust R22 for full-scale reading on meter. See Figure 5.5.

i. Set FUNCTION Switch to 90° and RANGE Switch to 1V (10 x overload).

j. Adjust C11 for zero reading on meter. See Figure 5.5.

k. Repeat steps f through j until best results are obtained. This is required due to the interaction of the two controls.

2. FOR INSTRUMENTS WHICH OPERATE AT PHASE SENSITIVE FREQUENCIES BELOW 160Hz OR ABOVE 1KHz, CONNECT AS IN FIGURE 5.4D.

a. Set the RANGE Switch to the 1V position and the FUNCTION Switch to TOTAL. (In Model 213C instruments, INPUT DIRect/TRANSformer Switch to DIRect.)

b. Apply a 1V ±0.5%, 50Hz signal to the SIGnal input terminals. Monitor with meter which has a frequency response flat within ±0.5%.

c. Adjust R22 for full-scale reading on the meter. See Figure 5.5.

d. Reset the SIGnal to 10KHz, 1V ±0.5%.

e. Adjust C11 for a full-scale reading on the meter. See Figure 5.5.

f. Recheck Steps b through e, readjusting as necessary. The 1000:1 input attenuator is now "broad-banded" and will have minimal phase shift.

5.6.3 DEGREES PHASE DIAL ALIGNMENT ON PHASE SHIFTER POTENTIOMETER, R4.

(This should be checked before proceeding to Phase Alignment.)

The following is a procedure for mechanically aligning the DEGREES Phase Dial on the shaft of the phase shifter potentiometer (R4). This is necessary in the event that a DEGREES Phase Dial, Phase Potentiometer, or both are disassembled or replaced. The 0° and 90° points on the DEGREES Phase Dial must be aligned to coincide with the taps of the potentiometer. This should only be done using a high impedance ohmmeter (i.e. HP412) as damage to the precision phase potentiometer can occur if excessive voltage is applied.

CAUTION

DO NOT use Simpson, Triplett, or other VOM.

A. Turn power off.

B. Set FUNCTION Switch to any PAV position.

C. Connect the ohmmeter between the wiper of R4 and the CCW tap point and rotate DEGREES Phase Dial for minimum resistance reading. Loosen DEGREES Phase Dial clamping screws and shift it until dial reading is exactly 90°. Tighten clamping screws. Connect ohmmeter between the wiper of R4 and the CW tap point and rotate DEGREES Phase Dial until wiper of R4 is on CW tap point (minimum resistance reading). The DEGREES Phase Dial should now read 0°. If not, note the difference and reposition dial so as to achieve the best compromise reading between the two taps. For example, if the 0° point reads low, the 90° point should read high by the same amount. Fully tighten knob set screw and recheck to make sure DEGREES Phase Dial has not slipped during tightening.

5.6.4 PHASE ALIGNMENT.

This alignment will adjust the instrument for zero phase shift between the signal and reference channels.

A. Connect the Model 213 as shown in Figure 5.4C. If a Phase Generator is not available, a precise 90° phase shifted signal may be generated as indicated in Figure 5.4B.

B. Set the FUNCTION Switch to FUNDamental, RANGE Switch to 0.01V.

C. Adjust the Variable Voltage Source to cause a full-scale reading on the meter.

D. Set the FUNCTION Switch to REFerence ADJust. Set the REFerence ADJust Control to the red-line mark on the meter.

E. Set FUNCTION Switch to 0°, DEGREES Phase Dial to 0°.

F. Set RANGE Switch to 0.001V (10 X overload) and adjust PHASE Control (R98) (See Figure 5.5) to cause the meter to read 0.

G. Set FUNCTION Switch to 90° and DEGREES Phase Dial to 90°.

H. Meter should read zero. If an error exists, re-adjust PHASE ADJust Control (R98) to divide the error between Steps F and G.

5.6.5 PHASE BRIDGE ALIGNMENT.

(Be sure to perform 5.6.4 before this procedure)

Note

The following procedure requires the use of an accurate Phase Generator. If a generator is not available, use the procedure in 5.6.5B.

A. Procedure Using an Accurate Phase Generator

1. Connect the Model 213 as in Figure 5.4C.

2. Set the FUNCTION Switch to FUNDamental.

3. Set RANGE switch to 0.01V.

4. Adjust the Variable Voltage Source to cause a full-scale reading on the meter.

5. Set FUNCTION Switch to REFerence ADJust position and set the REFerence ADJust Control for red line on the meter.

6. Set FUNCTION Switch to 0°.

7. Set Phase Dial to 90°.

8. Set RANGE Switch to 0.001V position.

9. Set Phase Generator for 0° phase shift.

10. Adjust R16 for a meter null.

11. Set Phase Dial to 45°.

12. Set Phase Generator for a 135° phase shift.

13. Adjust R8 for a meter null.

14. Set FUNCTION Switch to 90°.

15. Set Phase Generator for a 45° phase shift.

16. Adjust R9 for a meter null.

17. Repeat Steps 6 through 16 to obtain best settings, as they are interactive.

B. Alternate Procedure

1. Connect the Model 213 as in Figure 5.4A to obtain 0° signal input. Using a 100V reference level into the REFerence input terminals, set FUNCTION Switch to REFerence ADJust position and set REFerence ADJust Control to cause the meter to read red-line value.

2. Set FUNCTION Switch to 90°. Set DEGREES Phase Dial to 0°. Set RANGE Switch to 0.001V.

3. Inject a 0.010V (10 X overload) 0° signal into the SIGnal input terminals.

4. Adjust R16 for a meter null.

5. With the Monitor Voltmeter, measure the voltage at TP2.

6. Connect the Monitor Voltmeter to TP3 and adjust R8 to obtain a reading exactly the same as measured at TP2.

7. Connect the Monitor Voltmeter to TP9 and adjust R9 to obtain a reading exactly the same as measured at TP2.

8. Repeat Steps 4 through 7 to obtain best settings as they are interactive.

5.6.6 OVERLOAD LAMP ADJUST

A. Set Function Switch to 90°.

B. Set Range Switch to 1.0 volts.

C. Feed in 12 volts RMS.

D. Adjust R116 so that the overload light is lit. It should be off when 11 volts is applied.

PROCEDURE FOR SELECTING R135 TRANS MODE PHASE SHIFT (2KHz or Above)

Note

This procedure is performed at the factory and is not required unless the Signal Isolation Transformer is replaced.

1. Set DIRect/TRANS Switch to DIRect. Set RANGE Switch to 100mV position.

2. Feed in 10V (Pre-specified Frequency) into Ref Input Terminals. Feed in 100mV to Sig Input Terminals (Pre-specified Frequency.)

3. Set FUNCTION Switch to Ref Adjust and adjust Ref Level for Red Line.

4. Set RANGE Switch to 10mV position. Set FUNCTION Switch to 90° and adjust Phase Dial for a Null.

5. Set DIRect/TRANS Switch to TRANS. Do not touch Phase Dial setting.

6. Select R135 so that meter indicates the same null reading as in Step 4.

7. Set RANGE Switch to 100mV position. Set FUNCTION Switch to 0° position. Meter shojuld read full scale.

8. If meter does not read full scale, it may be necessary to decrease C79 slighly, and then re-select R135 for a Null as in Step 6.

9. Repeat Step 7.

PROCEDURE FOR SELECTING C79 TRANS MODE PHASE SHIFT (2KHz or Below)

Note

This procedure is performed at the factory and is not required unless the Signal Isolation Transformer is replaced.

1. Set Direct-Trans Switch to Direct. Set Range Switch to 100mV position.

2. Feed in 10 Volts (Pre-specified Frequency) into Ref Input Terminals. Feed in 100mV to Sig Input Terminals.

3. Set Function Switch to Ref Adj and adjust Ref Level for Red Line.

4. Set Range Switch to 10mV position. Set Function Switch to 90° and adjust Phase Dial for a null.

5. Set Direct-Trans Switch to Trans. Do not touch Phase Dial setting.

6. Select a capacitor that will cause the meter to read between 0 and +3 small divisions.

7. Set Range Switch to 10V position and apply a 100V input signal. Meter should read 0 ±3 small divisions.

T1 - PHASE SHIFT BALANCE TRIM SELECTION (Frequencies Below 400Hz)

Note

This is normally a factory adjustment. It should only be necessary to perform this trim in the field if T1 is replaced.

The purpose of this procedure is to balance the phase shift of the two secondary voltages (E31 and E27) with respect to the center tap (E28).

1. Apply 10V Reference to Ref Input Terminals and adjust for Red line.

2. Set FUNCTION Switch to 90°.

3. Set Phase Dial to 90°.

4. Set RANGE Switch to 1mV position.

5. Measure voltage at E31 and E27 with respect to E28 using H.P. VTVM or equivalent. If voltages are unequal by more than 5%, place a resistor from E31 to E28 or from E27 to E28 so that these voltages are equal to within 5%. (NOTE: At frequencies above 75Hz, a capacitor will be more effective than a resistor in achieving this balance.)

6. Apply 10mV RMS at 90° Phase Shift with respect to the reference to the Signal Input Terminals.

7. Adjust R98 for a Null on meter.

8. Set FUNCTION Switch to 0°.

9. Set Phase Dial to 0°.

10. Meter should read a NULL. If the meter does not read 0 2 small divisions, Tl will require a trim. NOTE: If the pre-specified operating frequency is 75Hz or above, the trim will be a resistor. If below 75Hz, the trim will be a capacitor. For example, 120Hz might require a resistor of approximatelyy 6.8k , 50Hz might require a capacitor of approximatelyy .018 f.

11. Select a trim (R or C depending on frequency) that will reduce the Null to 0 (less than 2 small divisions) and connect it between E31 and E28.

12. If connecting a trim across E31 and E28 causes the Null to increase in the same direction, repeat the above procedure substituting 0° for 90° in Steps 2 and 3 and substitute 90° for 0° in Steps 7 and 8. Then connect the trim across E27 and E28.

13. Perform steps 4.10, 4.11 and 4.12, then repeat steps 1 through 9 as there may be slight interaction.

5.6.7 FREQUENCY RESPONSE: (See Figure 5.4D)

A. Set FUNCTION Switch to the TOTAL Mode. Set RANGE Switch to 0.1V. Set INPUT TRANSformer/DIRect Switch to DIRect (Model C only).

B. Using the Variable Voltage Source, inject a signal equal to 0.09V at 400Hz*. Monitor this input voltage with

(text continued on page 5.14)

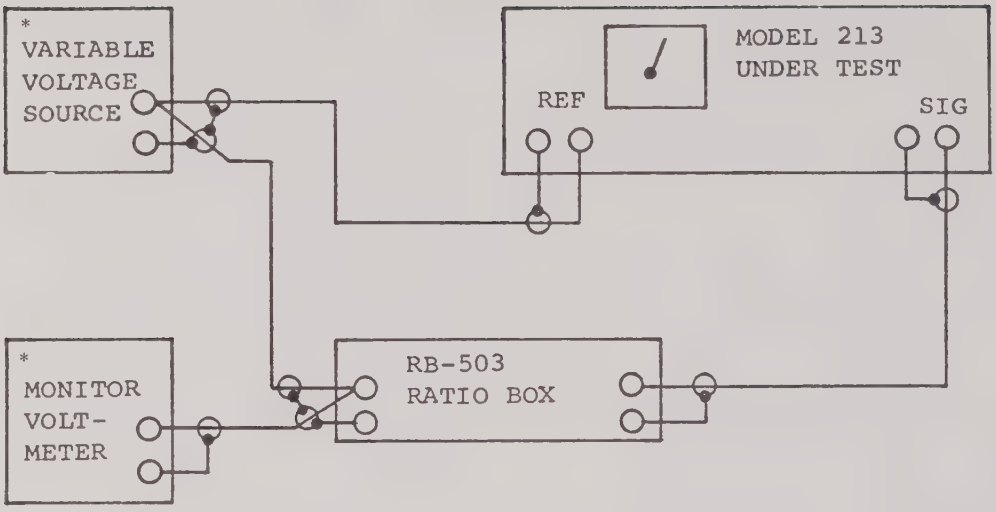
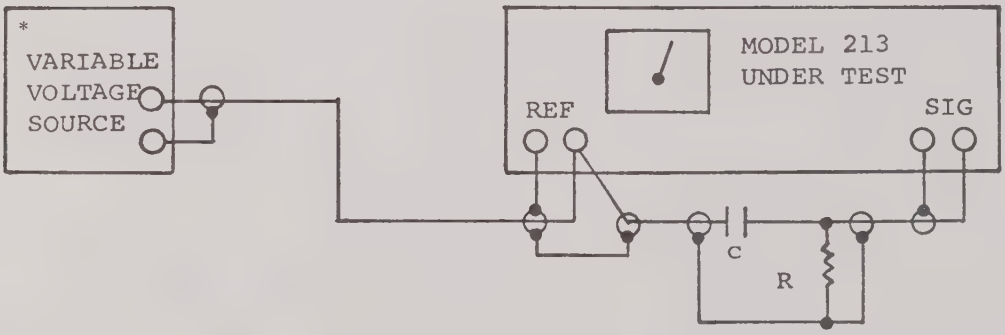


Figure 5.4A



400Hz

C = 500pf

R = 80Ω

For other frequencies

X_C approx. 10000 times R

R less than 200Ω

Figure 5.4B

*For test equipment specifications see Table II Page 5.2.

Figure 5.4 Test Circuits (Sheet 1 of 2)

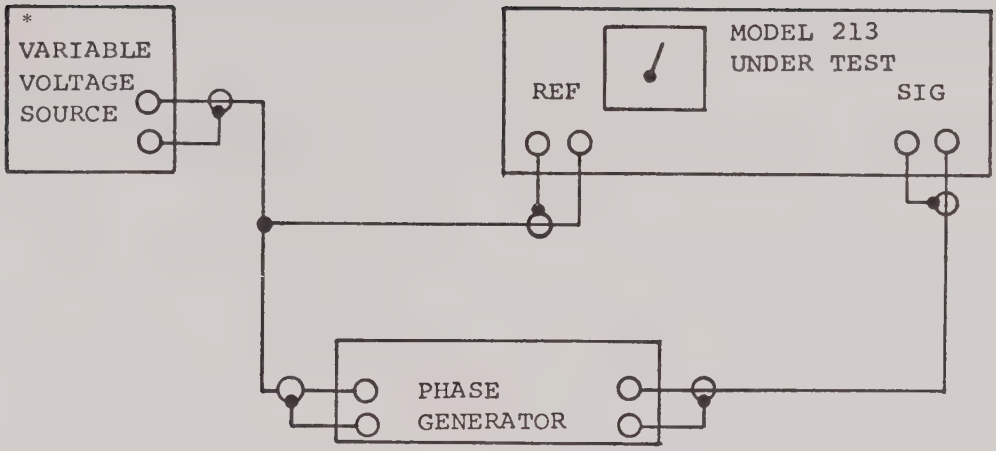


Figure 5.4C

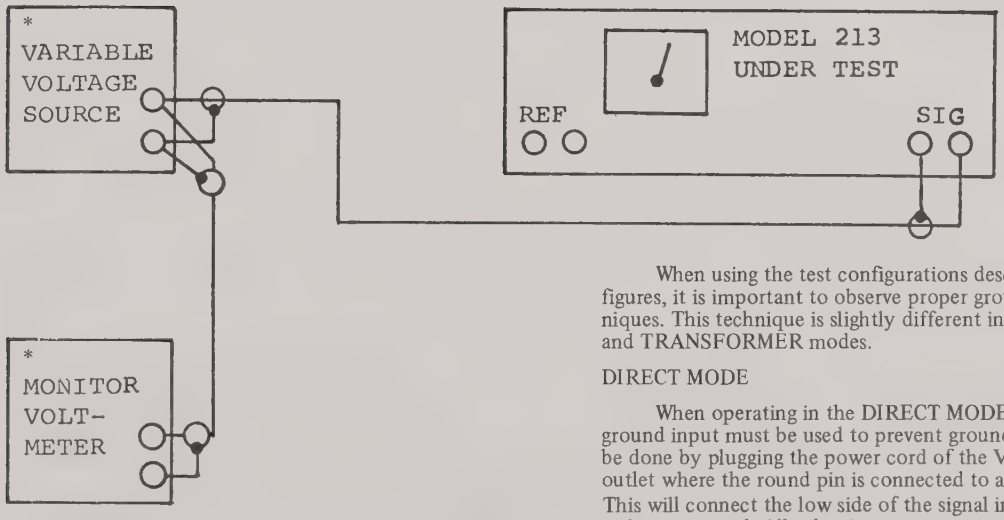


Figure 5.4D

*For test equipment specifications see Table II, Page 5.2.

When using the test configurations described in these figures, it is important to observe proper grounding techniques. This technique is slightly different in the DIRECT and TRANSFORMER modes.

DIRECT MODE

When operating in the DIRECT MODE, a single house ground input must be used to prevent ground loops. This can be done by plugging the power cord of the VM-213 into an outlet where the round pin is connected to a house ground. This will connect the low side of the signal input terminals to house ground. All other instruments connected to this low side must be then isolated from house ground by appropriate isolation plugs (3 pin to 2 pin adapters, not utilizing the ground lead).

TRANSFORMER MODE

When operating in the TRANSFORMER MODE, care must be taken to avoid common mode voltages between the signal input and the chassis-circuit ground of the instrument. This can be accomplished by connecting the low side of the input to the chassis of the VM-213 or to a house ground provided the round pin of the power plug is connected to house ground as above.

Figure 5.4 Test Circuits (Sheet 2 of 2)

the Monitor Voltmeter. (It is necessary that the frequency response be flat to within 0.5% over a range of 10Hz to 100KHz).

C. Sweep the frequency of the Variable Voltage Source from 10Hz to 100KHz and maintain a constant amplitude output. Meter should indicate a 0.09V ± 2% from 20Hz to 50KHz, and 0.09V ±5% from 10Hz to 100KHz.

D. Switch RANGE Switch to 1.0V and set Variable Voltage Source to 0.9V and repeat Step C.

Note

Meter should read 0.9V instead of 0.09V.

E. If the voltage peaking is excessive at 100KHz increase the value of C95. If the roll-off is excessive at 100KHz, decrease the value of C95 until the above specifications are met.

*Use the pre-specified phase-sensitive operating frequency.

5.7 TROUBLESHOOTING.

5.7.1 A troubleshooting table for the Phase Angle Voltmeter is presented in Table III. The troubleshooting table lists TROUBLE indications and denotes the PROBABLE CAUSE based on the observed symptoms.

To support troubleshooting operations, see the following maintenance diagrams: schematic diagram, Figure 5.6; and parts location and identification diagram, Figure 5.5 (Refer to the Parts List in Section VI for replacement part data.)

5.7.2 A circuit voltage table is also provided as an aid to troubleshooting. See Table IV.

Table III. Troubleshooting

Trouble	Probable Cause
Meter Lamps do not light when power is applied	Check fuse F1 and Meter Lamps
Meter Pegs on any position of RANGE Switch	No -15VDC at TP7. Check Q2, CR6 and/or associated components.
Meter reads to the left of zero in the TOTAL and FUNDamental Modes.	No +15VDC at TP8. Check Q1, CR5, and/or associated components.
Meter indicates in FUNDamental Mode but not in TOTAL Mode.	Check Z6B and associated circuitry.
Meter indicates in TOTAL Mode but not in FUNDamental Mode.	Check Z6A, Signal Filter Z7, and associated circuitry.
Meter indicates in REFerence ADJust Mode but does not indicate in TOTAL or FUNDamental Modes	If an AC signal appears at TP10, the trouble is probably in the Range Attenuator or check for an open switch contact on S1-B or S2-D1 and D2. If an AC signal does not appear at TP10, check the Signal Isolation Amplifier or the 1000:1 Attenuator.

Table III. Troubleshooting (Cont'd)

Trouble	Probable Cause
Inaccurate meter readings on one or more specific ranges.	Check Range Attenuator resistors R35 through R41.
Meter indicates on the lower ranges (0.1V or below) but does not indicate on the upper ranges (0.3V or above).	Check 1000:1 Attenuator components C9, C11, C12, R22, R23, and R24.
Meter indicates in TOTAL, FUNDamental, and REFerence ADJust Modes but not in 0° or 90° Modes.	Check for presence of 30V peak-to-peak square waves at TP5 and TP6. They should be 180° out-of-phase with each other. If they are not observed, then check Z4 and associated circuitry. If they are observed, check S2-F2 and S2-G1 for proper continuity in positions 4 through 7. If that is OK, then replace Z8 Detector Module.
Meter indicates TOTAL and FUNDamental Modes but not in 0°, 90° or REFerence ADJust Mode.	Check Reference Filter Z2, Reference Isolation Amplifier Z3, Reference Phase Bridge, or Reference Isolation Transformer T1. Note: In order to obtain a red line indication on the meter in REFerence ADJust position, the following approximate voltages should be: Z3 pin 2 - 1.4V RMS TP11 - 1.1V RMS
Meter does not indicate in any position of the FUNCTION Switch.	Check Z9, Z5, and associated circuitry. Note: For a full-scale deflection of the meter, the following voltages with their related positions of the FUNCTION Switch should be at TP1: TOTAL Approx. +415mV DC FUND Approx. +415mV DC *0° Approx. +415mV DC *90° Approx. 0V DC *Phase Dial set to 0° and 0° phase shift between Reference and Signal inputs. REFerence ADJust set for 1.1V RMS at TP11.
Proper voltages appear at TP1 and the meter still does not indicate	Check R113, R114, C70, CR13, and CR14, and S2-C1 and C2. If still no indication, replace meter.
Meter indicates in Direct Mode but not in Transformer Mode	Check for open Signal Isolation Transformer T3 or defective S5.
Meter indicates properly in 0°, 90°, 180°, and 270° when REFerence ADJust is set for a 1.1V RMS reading at TP11, but fails to operate in the REFerence ADJust, TOTAL, and FUNDamental Modes.	Check S2-F2 and S2-G1 continuity. If it still does not indicate, replace Detector Module Z8.
Overload Lamp remains lit or does not light.	Check Q5, Q6, and associated circuitry.

Table IV. Circuit Voltages

Note

All voltage measurements should be made with respect to circuit ground. Ripple measurements at TP7 and TP8 should be referenced to the power supply circuit ground at the plus end of C8 and the minus end of C7.

Voltages listed in the Table are nominal and based on the following conditions, unless otherwise noted:

1. Range Switch set to 10V.
2. Ref. Int.-Ext. Switch to Ext.
3. Signal Input Switch to Direct.
4. Phase Dial set to 0°.
5. Sig. Input 10V RMS 400Hz 0° Phase.
   Ref. Input 10V RMS 400Hz 0° Phase.
6. Ref. Adj. set for Red Line.

Location	Voltages	Function Switch Position
TP8	+15VDC 3mV RMS	0°
TP7	-15VDC 3mV RMS	0°
TP10	32mV RMS	0°
Z6A Pin 12	145mV RMS	0°
Z7A Pin 2	135mV RMS	0°
S2-E Arm	120mV RMS	0°
S2-E Arm	120mV RMS	Total
TP2	28mV RMS (90° Signal)	0°
TP3	28mV RMS (0° Signal)	0°
TP9	28mV RMS (180° Signal)	0°
Z3A Pin 12	28mV RMS	0°
Z3A Pin 12	20mV RMS 28mV RMS	Phase Dial to 45° Phase Dial to 90°
Z3B Pin 2	1.6V RMS	0°
Z2A Pin 12	1.56V RMS	0°

Table IV. Circuit Voltages (Cont'd)

Location	Voltages	Function Switch Position
TP11	1.3V RMS	0°
TP5	30V pp ⊓⊔	0°
TP6	30V pp ⊔⊓	0°
TP4	560mV RMS	0°
TP1	+415mVDC +415mVDC +415mVDC 0VDC +415mVDC 0VDC	Total Fundamental 0° 90° 180° 270°

COMPONENT LOCATION TABLE

	R	C	CR	Z	Q	TP
1	F7	F5	D2	--	D3	D5
2	F7	E4	D2	D3	D2	E6
3	F8	E4	D2	E5	E9	E6
4	G8	F5	D2	C5	E9	D6
5	F5	C2	D3	D6	C5	E5
6	F6	D2	D3	E8	C4	B5
7	F5	E2	D10	C8	E7	E3
8	F5	E2	D10	C6	E7	E3
9	F5	F8	D9	D5		F6
10	E5	F9	D9			D9
11	F5	F10	D9			B4
12	F5	F10	D9			D6
13	F5	E9	--			
14	F5	E10	--			
15	E5	E9	D5			
16	E5	E9	D5			
17	F6	D9	E9			
18	D3	D9				
19	E2	D9				
20	D3	E8				
21	E2	F8				
22	F9	E8				
23	F9	E8				
24	F10	F8				
25	E10	E8				
26	E9	E6				
27	E9	D5				
28	E9	D5				
29	E9	E6				
30	E9	D4				
31	F8	E3				
32	E9	E3				
33	E9	D3				
34	D9	D3				
35	C9	D3				

	R	C
36	C9	D4
37	C9	C4
38	C9	D4
39	D9	C4
40	D9	D4
41	D9	D4
42	E8	D4
43	E8	C4
44	E8	C4
45	E8	D8
46	E8	C8
47	E8	C8
48	E8	B7
49	F8	C8
50	E8	B8
51	F8	B9
52	E9	C9
53	F9	C8
54	E6	C8
55	E6	C8
56	G3	B8
57	D5	C7
58	D4	D7
59	E3	E6
60	D3	D6
61	E4	D6
62	D3	D5
63	D4	D6
64	D4	B7
65	D3	C5
66	C4	B5
67	C4	B5
68	D4	D6
69	D8	D6
70	D8	E7

	R	C
71	C7	D6
72	C8	D5
73	B7	C5
74	C7	--
75	C8	C5
76	B8	D5
77	B8	E5
78	C8	E5
79	B9	--
80	B9	--
81	C9	E9
82	E9	E4
83	--	D4
84	--	D8
85	--	C9
86	--	D6
87	--	D4
88	--	D4
89	--	B7
90	C6	B9
91	E6	B6
92	E6	
93	D5	
94	--	E8
95	C5	E9
96	D6	
97	--	
98	A4	
99	C5	
100	C5	
101	B5	
102	B5	
103	B5	
104	D6	
105	D6	

	R
106	D6
107	D5
108	D5
109	D5
110	D5
111	C5
112	--
113	D7
114	D7
115	D5
116	D5
117	C5
118	C5
119	C5
120	C4
121	C5
122	F3
123	F3
124	--
127	D4
128	E5
129	D4
130	E5
131	F8
132	B8
133	C5
134	B8
135	--
136	F4
137	F4
138	D5
139	E6
140	C4
141	E8
142	E5
143	E9

TO LOCATE A COMPONENT ON THE COMPONENT LOCATOR, LOCATE ZONE USING ABOVE TABLE (ZONE FOR R1 IS F7, ZONE FOR C55 IS C8). COMPONENT CAN THEN BE LOCATED ON COMPONENT LOCATOR WITHIN THE ZONE INDICATED.

REV A 8-31-73

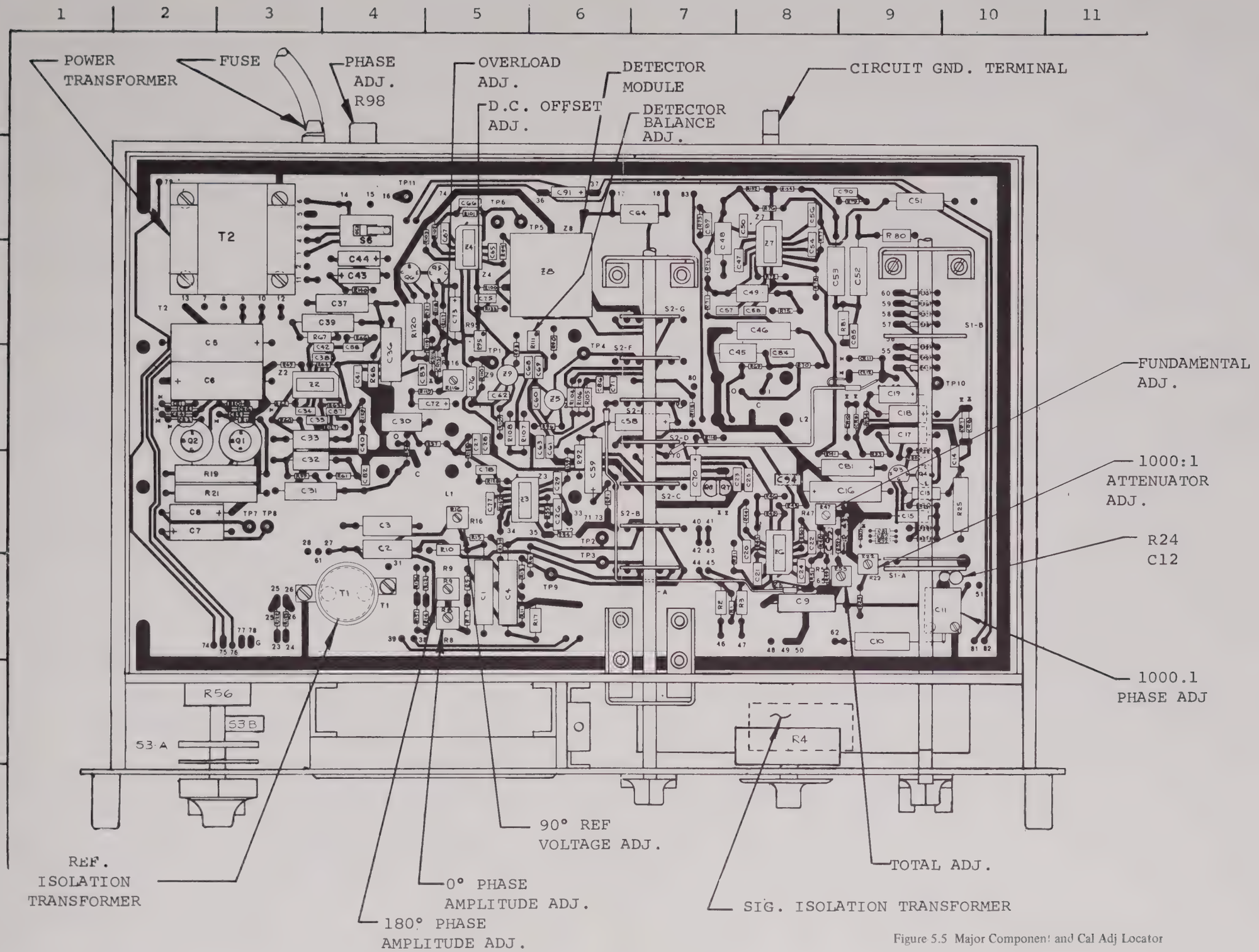


Figure 5.5 Major Component and Cal Adj Locator

SIGNAL FILTER

REF FILTER

SQUARING AMPLIFIER

DETECTOR AMPL.

DETECTOR AMPL

METER DRIVE CIRCUIT

OVERLOAD CIRCUIT

DETECTOR MODULE

R45 10K,2% R46 300Ω,2% FUND ADJ. R47 200Ω R131 10K +15V

C20 100Pf C21 5Pf

R52 300Ω,2% R53 200Ω TOTAL ADJ. R51 10K,2%

C22 100Pf C23 .01μf C24 5Pf C25 .01μf

R69 3K,2% R70 5.1K,2% R71 16K,2%

C45 .033μf C46 .12μf

R72 12K

Z7A

R73 2K C89 33Pf C50 100Pf

R74 22K,2% C49,.1μf C48,.1μf C84 100Pf R75 300Ω 2% C47 390Pf

R76 2.7K,2% R77 8.2K,2%

C51 .15μf R132 10K +15V

R78 3.6K C57 .01μf -15V

Z7B

R80 7.5K,1% C52,.12μf C53,.12μf C85 100Pf R81 1.3K,1% C54 390Pf +15V C55 .01μf

R79 2K C90 33Pf C56 100Pf R134 10K +15V

S2-E 01 02 03 04 05 06 07 A

C58 100μf C59 100μf R92 5.11K R91 20K

+15V R106 5.1MEG R111 100K -15V DETECTOR BALANCE ADJ.

TP4

C60 150Pf C61 .01μf

Z5

R96 2.7K C63 .01μf -15V

C76 .022μf R110,43K±2% R113 5.6K,2% R114 2.7K,2%

R107 10.2K C62 150Pf +15V C69 .01μf

R108 5.1K,1% Z9 TP1

R109 5.1K C68 .01μf -15V R93 6.8MEG D.C. OFFSET ADJ. R95 100K +15V

Q7 2N3819 C70 22μf Q8 2N3819

S2-C2 01 02 03 04 05 06 07 A

S2-C1 01 02 03 04 05 06 07 A

E39 M1 E38

TP12

C72 1μf R115 5.1K

OVLD. LAMP ADJ. R116 10K

CR16 IN3069 CR15 IN3069

R119 22K R121 20K Q5 2N697 R120 1.2K 2W Q6 2N697 E82 E37 C91 18μf 15V D31 E36 E81

R117 100K C73 18μf R118 10Ω -15V

TP11

R90 47K

C44 47μf E16

R98 10K PHASE ADJ. E18 E17

C64 .05Gs

S2-G2 01 02 03 04 05 06 07 A

C65 5Pf +15V

R99 2.7K Z4A R101 24K C66 500Pf R102 6.2K

R100 15K C75 82Pf -15V R133 15K

Z4B R103 6.2K

C67 20Pf

TP6

TP5

S2-F1 01 02 03 04 05 06 07 A

Z8

S2-F2 01 02 03 04 05 06 07 A R104 5.11K 1% C71 10Pf

S2-G1 01 02 03 04 05 06 07 A R105 5.11K 1% C86 10Pf

R67 7.5K,1% C37,.12μf C39,.12μf C38 390Pf R68 1.3K,1% C40 .01μf C82 100Pf C83 100Pf

RG3 2.7K,2% RG4 8.2K,2% Z2B C36 .15μf RG5 3.6K C88,33Pf RG6 2K C42 100Pf R140 10K C41 .01μf -15V +15V

C43 47μf

C35 100Pf R129 10K

FREQUENCY COMPONENT TABLE

R57 RG9	R58 R70	R59 R71	R60 R74	R61 R75	R63 R76	R64 R77	R67 R80	R68 R81	R62 R72	R65 R78	C1	C2	C3	C4	C30 C45	C31 C46	C32 C49	C33 C48	C36 C51	C37 C52	C39 C53	C64	R130
10K	16K	56K	82K	1K	9.1K	27K	24K	4.3K	43K	12K	5.6	.27	.27	5.6	.1	.39	.33	.33	.47	.39	.39	.68	51Ω
10K	16K	56K	82K	1K	9.1K	27K	24K	4.3K	43K	12K	3.3	.15	.15	3.3	.068	.27	.22	.22	.33	.27	.27	.39	
10K	16K	56K	82K	1K	9.1K	27K	24K	4.3K	43K	12K	2.2	.1	.1	2.2	.047	.18	.15	.15	.22	.18	.18	.27	
3K	5.1K	16K	22K	300	2.7K	8.2K	7.5K	1.3K	12K	3.6K	1.5	.068	.068	1.5	.1	.39	.33	.33	.47	.39	.39	.18	
											1.0	.047	.047	1.0	.068	.27	.22	.22	.33	.27	.27	.12	
											.68	.033	.033	.68	.047	.18	.15	.15	.22	.18	.18	.082	
											.47	.022	.022	.47	.033	.12	.1	.1	.15	.12	.12	.056	100Ω
											.33	.015	.015	.33	.022	.082	.068	.068	.1	.082	.082	.039	
											.22	.01	.01	.22	.015	.056	.047	.047	.068	.056	.056	.027	
											.15	.0068	.0068	.15	.01	.035	.027	.027	.047	.033	.033	.018	
											.10	.0047	.0047	.10	.0068	.022	.018	.018	.027	.022	.022	.0082	
											.068	.0027	.0027	.068	.0047	.015	.012	.012	.018	.015	.015	.0047	
											.039	.0018	.0018	.039	.0027	.01	.0082	.0068	.012	.01	.01	.0033	
											.027	.0012	.0012	.027	.0018	.0068	.0068	.0068	.0082	.0068	.0068	.0022	
3K	5.1K	16K	22K	300	2.7K	8.2K	7.5K	1.3K	12K	3.6K	.018	910Pf	910Pf	.018	.0012	.0047	.0039	.0039	.0056	.0047	.0047	.0015	

NOTE:

1- ALL RESISTORS ARE 1/4 W, ±5% UNLESS OTHERWISE SPECIFIED.
2- SCHEMATIC AS SHOWN IS 400Hz, FOR OTHER FREQUENCIES SEE COMPONENT TABLE FOR VALUE CHANGES.
3- * DENOTES SELECT AT TEST.
4- SG IS SHOWN IN 115V POSITION.
5- * * FACTORY SELECTED RESISTOR OR CAPACITOR DEPENDING ON FREQUENCY (IF REQUIRED).

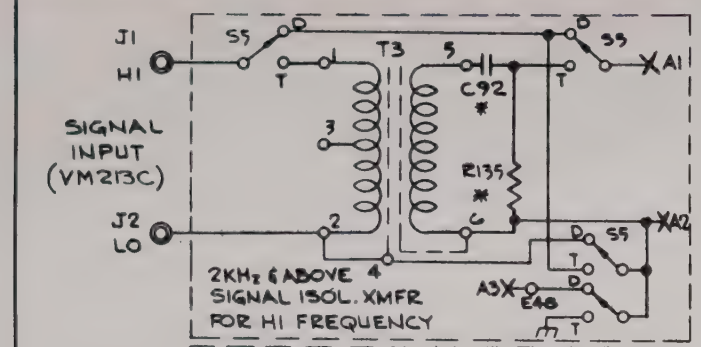
● INTENAL TRIMPOT
Ⓘ EXTERNAL ADJUSTMENT
● TEST POINT

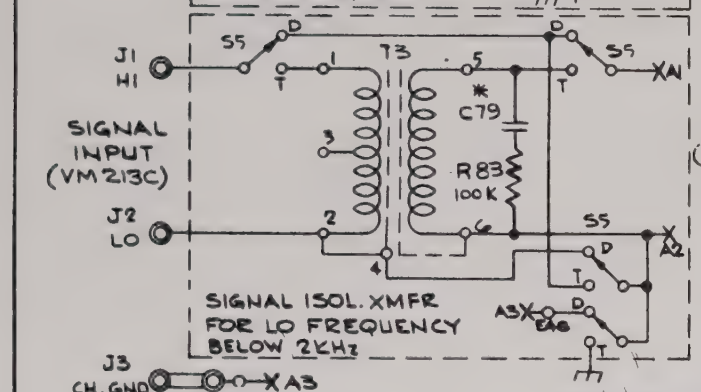
⏚ CIRCUIT GND.
⏚ CHASSIS GND.

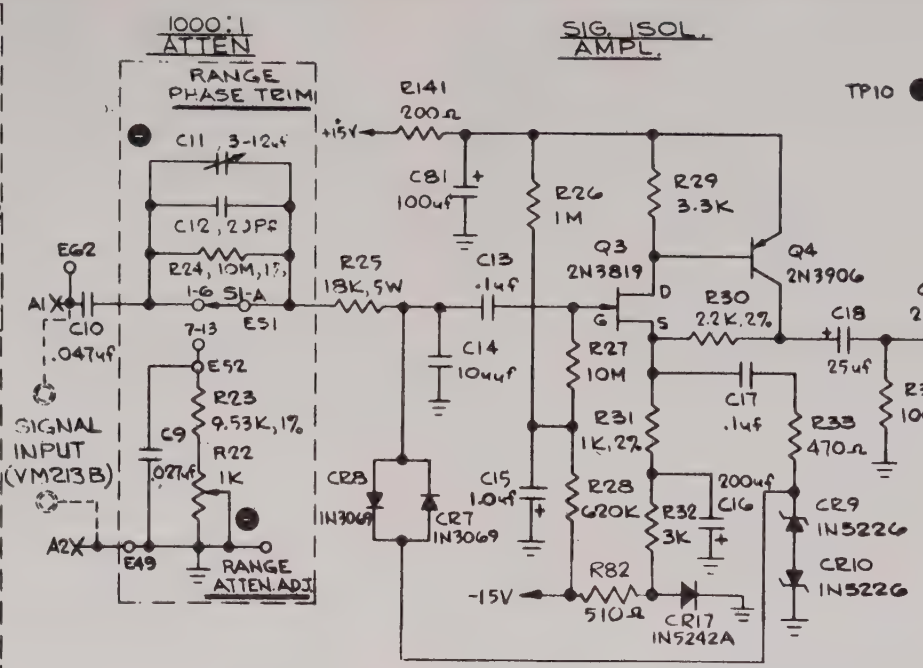
6- Z2,3,4,6,7 ARE MC1437L.
Z5,9 ARE 301A.

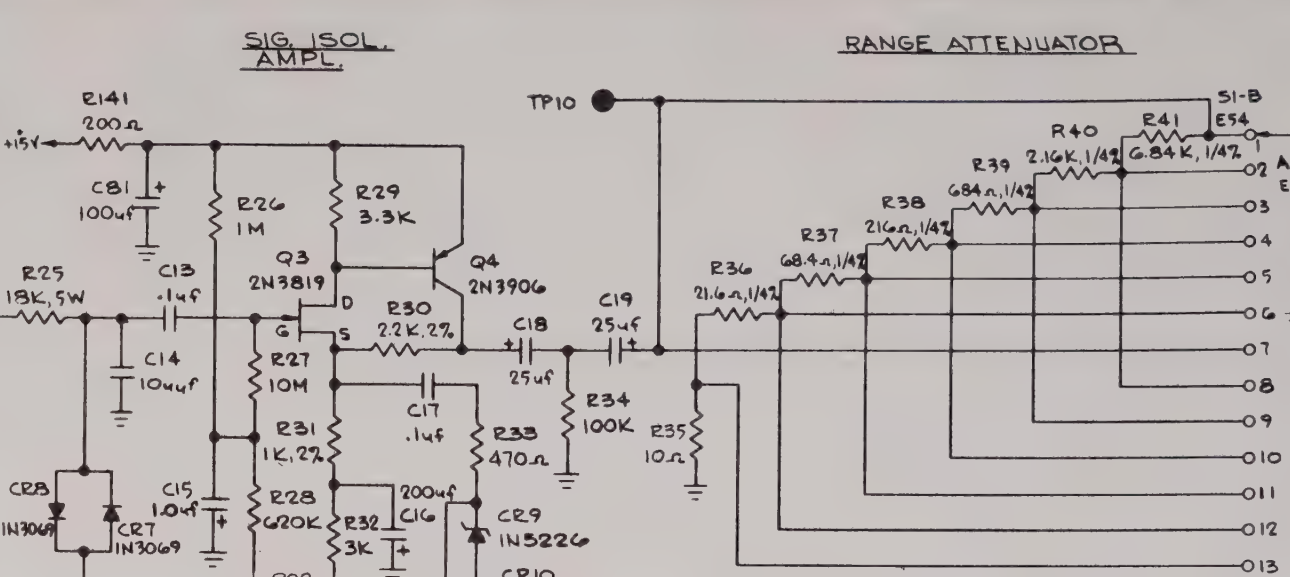
7- *** SELECT AT TEST FOR PHASE GRADIENT MATCH
BAND 1 THRU 3 R61: (910Ω, 1000Ω, OR 1100Ω) M.F. 2%
BAND 4 THRU 15 R61: (270Ω, 300Ω, OR 330Ω) M.F. 2%

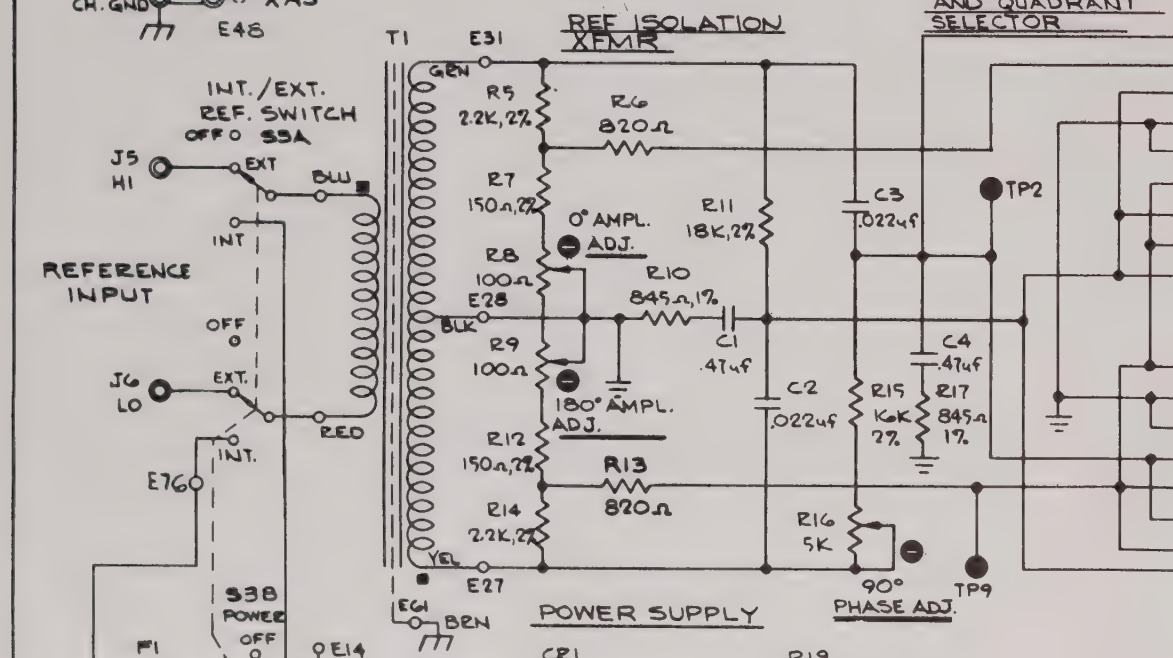
Figure 5.6 Schematic

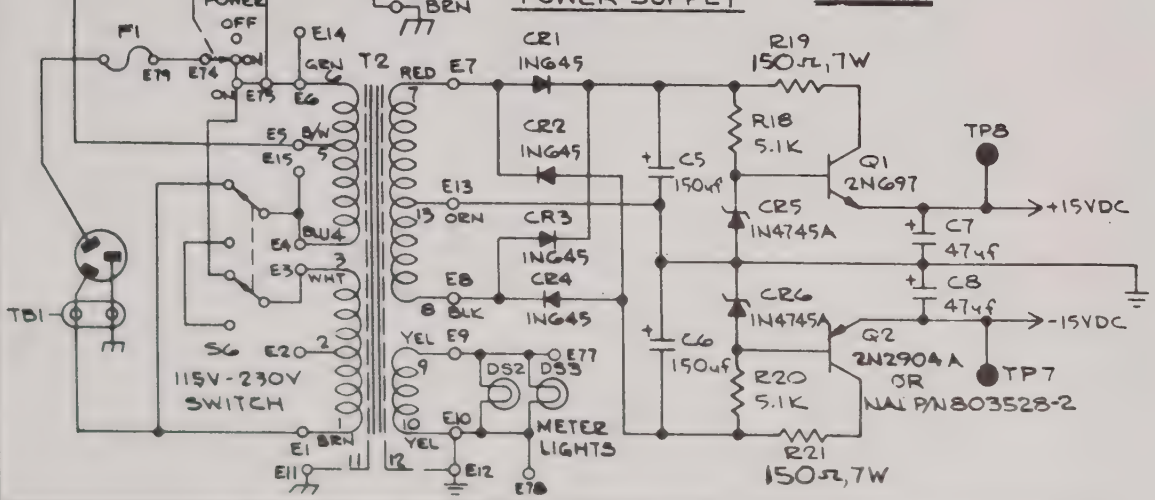


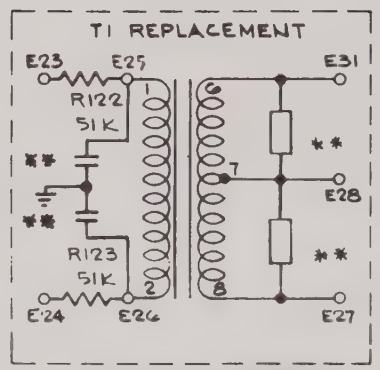




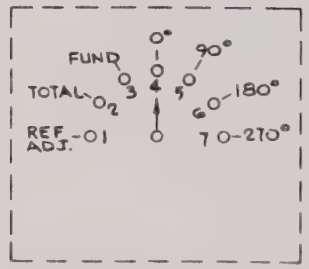




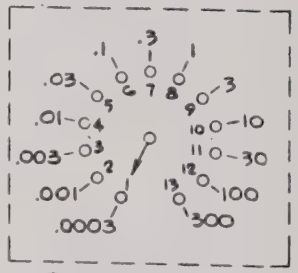




ALTERNATE REFERENCE
FOR FREQUENCY UNDER 400Hz



FUNCTION SWITCH (S2)



RANGE SWITCH (S1)

BAND	BAND WIDTH
1	30Hz - 39 Hz
2	40 Hz - 59 Hz
3	60Hz - 92 Hz
4	93Hz - 137 Hz
5	138Hz - 204 Hz
6	205Hz - 309Hz
7	310Hz - 464Hz
8	465Hz - 699Hz
9	700Hz - 1.05 KHz
10	1.06KHz - 1.57KHz
11	1.58KHz - 2.36KHz
12	2.37KHz - 3.55KHz
13	3.56KHz - 5.34KHz
14	5.35KHz - 7.9KHz
15	8KHz - 10KHz

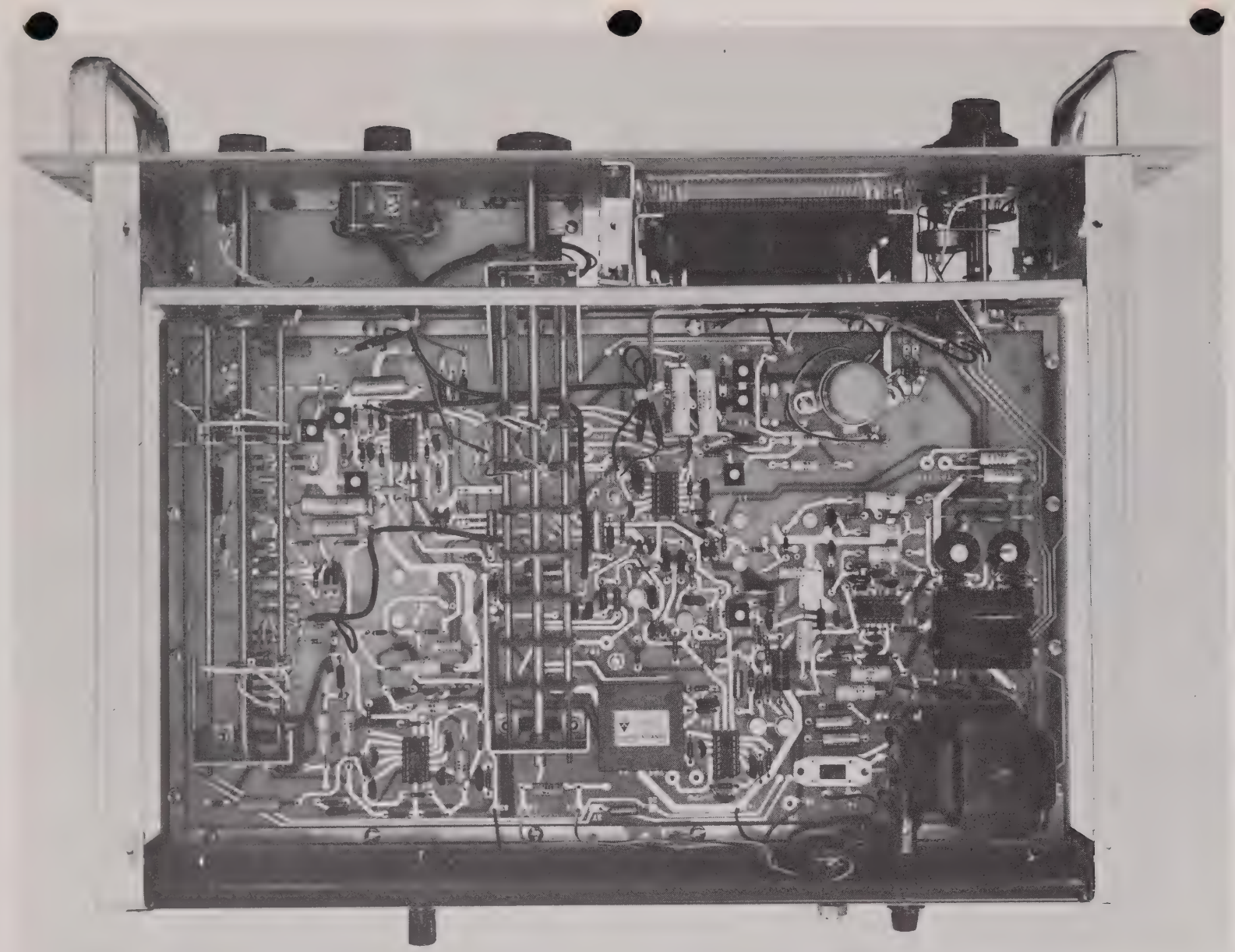


Figure 5.7 Top View, Cover Removed

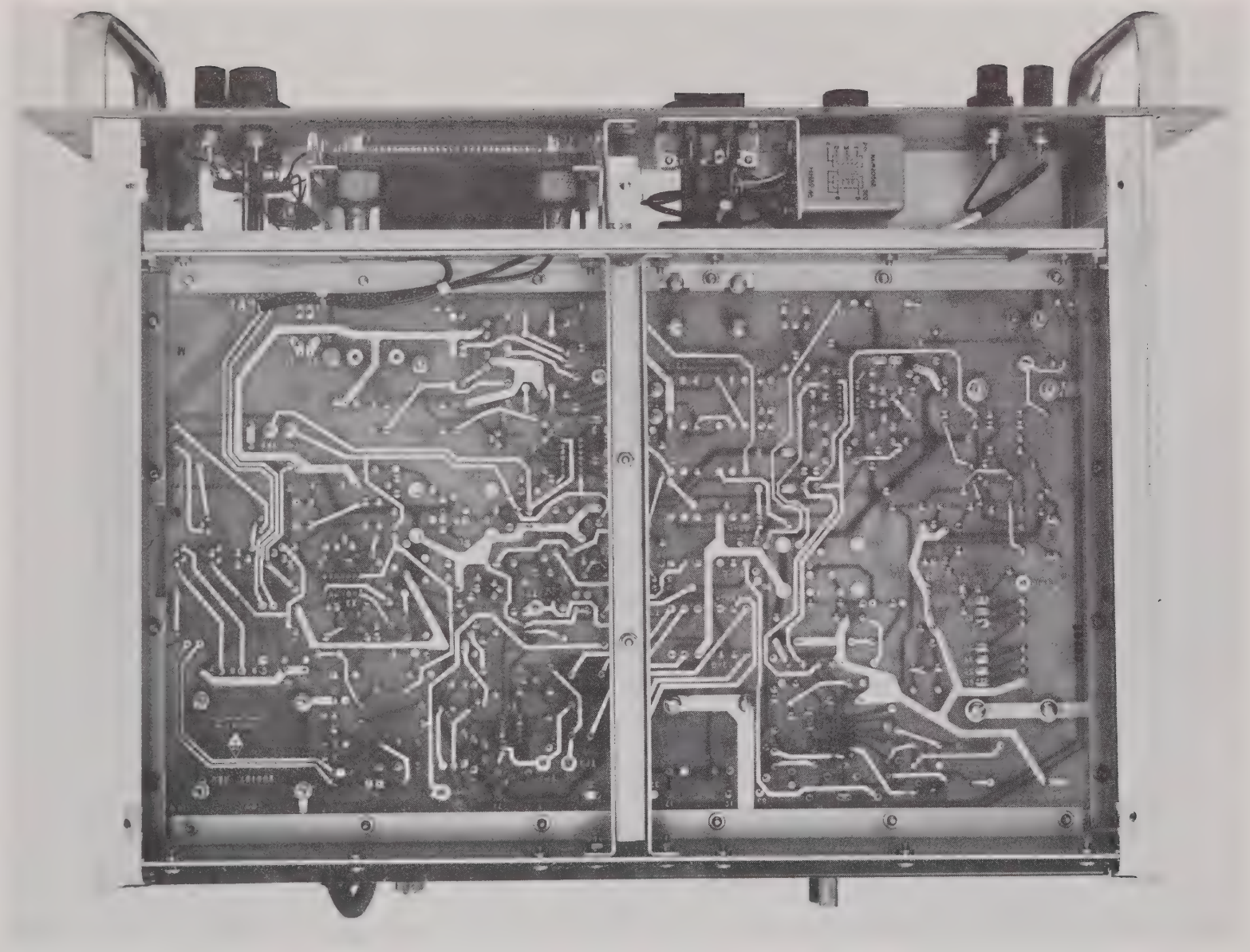


Figure 5.8 Bottom View, Cover Removed

SECTION VI

REPLACEMENT PARTS LIST

CODE LIST OF MANUFACTURERS

CODE IDENT.	MANUFACTURER
01121	Allen Bradley, Milwaukee, Wisconsin
01295	Texas Instruments, Inc., Semi-Conductor Div., Dallas, Texas
04713	Motorola Semiconductor Products, Phoenix, Arizona
06001	G. E. Co. Cap. Dept., P. O. Box 158 Irmo, S. C.
06751	Components Inc., Semcor Div., Phoenix, Arizona
07263	Fairchild Semiconductor, Mountain View, California
08806	G. E. Minature Lamp Div., Nela Park, Cleveland, Ohio
12040	National Semi-Conductor Corp., Danbury, Connecticut
12126	Kidco Inc., Medford, New Jersey
14655	Cornell Dubilier Elect. Corp., Newwark, New Jersey
16299	Corning Glass Works, Raleigh, North Carolina
24655	General Radio, West Concord, Mass.
27690	Vacohm Electronics Co. Inc., Haddonfield, New Jersey
31918	International Electro Exchange Inc., Minneapolis, Minn.
32997	Bourns, Riverside, California
56289	Sprague Elec. Co., North Adams, Mass.
70903	Belden Corp., Chicago, Illinois
72136	(Elmenco) Electro Motive Mfg. Co., Inc., Willimantic, Conn.
72619	Dialight Corp., Brooklyn, New York
72765	Drake Mfg., Harwood Heights, Illinois
75915	Little Fuse Inc., Des Plaines, Illinois
79727	Continentalwirt Electronics Corp., Philadelphia, Penn.
80183	Sprague Prod. Co., North Adams, Mass.
80223	United Transformer Co., Varick St., New York, New York
81073	Grayhill, LaGrange, Illinois
83330	H. H. Smith, Brooklyn, New York
84171	Arco Elec. Inc., Community Drive, Great Neck, New York
71590	Centralab Mfg. Corp., Milwaukee, Wisconsin
91637	Dale Electronics, Columbus, Nebraska
91674	Erie Elec. Mfg. Corp., Erie Pennsylvania

REPLACEMENT PARTS LIST

Note

Consistent with North Atlantic Industries' policy of continuously up-grading components and improving circuits, we reserve the right to substitute components which are functionally interchangeable for any of the parts shown in this parts list.

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
C5, C6	805652	2	Capacitor, Fixed, Elec. 150uf, 50V, -10% +100%	14655	BR150-50
C7, C8, C43, C44	801193	4	Capacitor, Fixed, Elec. 47uf, 20V, ±20%	56289	150D476X0020RZ
C9	802571	1	Capacitor, Fixed, Polystyrene, .027uf, 100V ±5%	84171	IPT-273J
C10	802395	1	Capacitor, Fixed, Film .47uf, 400V	56279	192P47394
C11	800102	1	Capacitor, Variable 3-12uuf	91674	503-041C0P017R
C12	807645	1	Capacitor, Fixed, Polystyrene, 20Pf, 630V ± 1pf	08111	611.2-20JP
C14	805603	1	Capacitor, Fixed, Ceramic 10Pf, 1000V ± .5pf	91674	831-000C0G0100D
C16	803060	1	Capacitor, Fixed, Elec. 200uf, 15V -10% +75%	56289	30D207G015DH4
C17, C13	804456	2	Capacitor, Fixed, Film .1uf, 80V ±10%	56289	192P1049R8
C18, C19	803342	2	Capacitor, Fixed, Elec. 25uf, 25V -10% +75%	56289	30D256G025CB0
C20, C22, C35, C42, C50,C56, C78, C82, C83, C84, C85	805638	11	Capacitor, Fixed, Ceramic 100Pf, 1000V ±10%	91674	831-000X5F0101K
C21, C24, C65	805619	3	Capacitor, Fixed, Ceramic 5Pf, 1000V ± .25pf	91674	831-000C0G0509C
C23, C25, C27, C28, C40, C41, C55, C57, C61, C63, C68, C69	803406	12	Capacitor, Fixed, Ceramic .01uf, 25V +80% -20%	91674	5835-000-Y5U-103Z
C26	805620	1	Capacitor, Fixed, Ceramic 5000Pf, 1000V ±10%	91674	811-000X5R0502K
C29	805602	1	Capacitor, Fixed, Ceramic 200Pf, 1000V ±10%	91674	831-000X5F0201K
C34, C38, C47, C54	800877	4	Capacitor, Fixed, Ceramic 390Pf, 600V ±10%	91674	831-000-X5F-391K
C58, C59	806726	2	Capacitor, Fixed, Elec. 100uf, 10V ±10%	06751	TS3K-10-1071
C60, C62	801365	2	Capacitor, Fixed, Mica 150Pf, 500V ±5%	72136	DM15-F151J
C66	805623	1	Capacitor, Fixed, Ceramic 500Pf, 1000V ±10%	91674	831-000X5F0501K
C67, C77	802638	2	Capacitor, Fixed, Mica 20Pf, 500V ±5%	72136	DM15-200J
C70	803453	1	Capacitor, Fixed, Elec. 22uf, 6V ±20%	56289	150D226X0006B2
C71, C86	804063	2	Capacitor, Fixed, Mica 10Pf, 500V ±10%	72136	DM10-100K
C72, C15	801092	2	Capacitor, Fixed, Elec. 1uf, 20V ±20%	56289	150D105X0020A2
C73, C91	806085	2	Capacitor, fixed, Elec. 18uf, 15V ±10%	06751	TS2K-15-186K
C75	801643	1	Capacitor, Fixed, Mica 82Pf, 500V ±5%	72136	DM-15-820J
C76	806687	1	Capacitor, Fixed, Film .022uf, 80V ±5%	06001	AE15R223J
C79, C92			Capacitor, Fixed, Mica Select at Test		
	802168		From 200uuf, 500V, ±5%	84171	SCDM10-201J
	802341		220uuf, 500V, ±10%	84171	DM15-221K
	802310		Nominal 250uuf, 500V, ±5%	84171	DM15-251J
	802311		270uuf, 500V, ±5%	84171	DM15-271J
	802342		300uuf, 500V, ±10%	84171	DM15-301K
	802242		330uuf, 500V, ±5%	84171	DM15-331J
	802312		360uuf, 500V, ±5%	84171	DM15-361J
	801786		390uuf, 500V, ±5%	84171	DM15-391J
	801971		470uuf, 500V, ±10%	84171	DM15-471K
	802313		510uuf, 500V, ±5%	84171	DM15-511J

REPLACEMENT PARTS LIST (Continued)

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
C81	805628	1	Capacitor, Fixed, Elec. 100uf, 20V ±10%	06751	TS4K-20-107K
C87, C88, C89, C90	801749	4	Capacitor, Fixed, Mica 33pf, 500V, ±10%	72136	DM15-330K
C94	802310	1	Capacitor, Fixed Mica 250pf, 500V, ±5%	72136	DM-15-251J
C95		1	Capacitor, Fixed Mica Select at Test Range 0pf to 39pf, 500V, ±5%	72136	Type DM-15-XXXJ
CR1, CR2, CR3, CR4	800323	4	Diode, 1N645	01295	1N645
CR5, CR6	804098	2	Diode, 1N4745A	04713	1N4745A
CR7,CR8,CR11, CR12,CR15,CR16	802924	6	Diode, 1N3069	07263	1N3069
CR9, CR10	807063	2	Diode, 1N5226	04713	1N5226
CR17	807124	1	Diode, 1N5242A	04713	1N5242A
DS1 (OVLD)	804507	1	Light Cartridge (red)	72765	407-603
DS2, DS3	803611	2	Light (Meter), GE#51	08806	GE#51
F1	803877	1	Fuse, .5A (115V Power) S.B.	75915	313.500
	807117	1	Fuse, .25A (230V Power) S.B.	75915	313.250
M1	202556	1	Meter	NAI	
Q1, Q5, Q6	804403	3	Transistor, 2N697	01295	2N697
Q2	803528-2	1	Transistor, (Special) (Replacement 2N2904)	NAI	
Q3	202837	1	Transistor, 2N3819 (Special)	NAI	
Q4	803661	1	Transistor, 2N3906	04713	2N3906
Q7, Q8	803662	2	Transistor, 2N3819	04713	2N3819
R1	802723	1	Resistor, Fixed, Comp. 43K, 1/4W ±5%	01121	CB4335
R2, R3	803238	2	Resistor, Fixed Dep. Carbon 39K, 1/4W ±1%	12126	M1/4-39K-±1%
R4	201568	1	Resistor, Variable 50K (Phase Dial)	NAI	
R5, R14, R30	806658	3	Resistor, Fixed Film 2.2K, 1/4W ±2%	16299	C4-2.2K±2%
R6, R13	803693	2	Resistor, Fixed Comp. 820Ω, 1/4W ±5%	01121	CB8215
R7, R12	806659	2	Resistor, Fixed Film 150Ω 1/4W ±2%	16299	C4-150Ω±2%
R8, R9	806721	2	Resistor, Variable 100Ω	80294	3389P100Ω
R10, R17	805616	2	Resistor, Fixed Film 845Ω, 1/4 W ±2%	16299	C4-845Ω±2%
R11	806660	1	Resistor, Fixed film 18K, 1/4W ±2%	16299	C4-18K±2%
R15	806680	1	Resistor, Fixed Film 16K, 1/4W ±2%	16299	C4-16K±2%
R16	806722	1	Resistor, Variable 5K	80294	3389P5K
R18, R20, R109, R115, R139	801397	5	Resistor, Fixed Comp. 5.1K, 1/4W ±5%	01121	CB5125
R19, R21	807110	2	Resistor, Fixed Wirewound 150Ω, 7W ±5%	80183	244E1515
R22	806725	1	Resistor, Variable 1K	80294	3389P1K
R23	805400	1	Resistor, Fixed Film 9.53K, 1/4W ±2%	16299	C4-9.53K±2%
R24	806664	1	Resistor, Fixed Film 10M, 1/2W ±1%	91637	HMF-1/2-10M±1%-T-1
R25	801362	1	Resistor, Fixed Wirewound 18K, 5W, ±3%	91637	RS-5-18K±3%
R26	802730	1	Resistor, Fixed Comp. 1M, 1/4W ±5%	01121	CB-1055
R27	803389	1	Resistor, Fixed Comp. 10M, 1/4W ±5%	01121	CB-1065
R28	802087	1	Resistor, Fixed Comp. 620K, 1/4W ±5%	01121	CB-6245
R29	803388	1	Resistor, Fixed Comp. 3.3K, 1/4W ±5%	01121	CB-3325
R31	806663	1	Resistor, Fixed Film 1K, 1/4W ±2%	16299	C4-1K±2%

REPLACEMENT PARTS LIST (Continued)

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
R32	801406	1	Resistor, Fixed Comp. 3K, 1/4W ±5%	01121	CB-3025
R33	803223	1	Resistor, Fixed Comp. 470Ω, 1/4W ±10%	01121	CB-4715
R34, R117	801986	2	Resistor, Fixed Comp. 100K, 1/4W ±5%	01121	CB-1045
R35	803000	1	Resistor, Fixed Film 10Ω, 1/8W ±1/4%	12126	M1/8-10Ω–±1/4%
R36	803431	1	Resistor, Fixed Film 21.6Ω, 1/8W ±1/4%, TC ± 150 PPM	27690	M60-*
R37	801478	1	Resistor, Fixed Film 68.4Ω, 1/8W ±1/4%, TC ± 150 PPM	27690	M60-*
R38	801477	1	Resistor, Fixed Film 216Ω, 1/8W, ±1/4%, TC ± 150 PPM	27690	M60-*
R39	801476	1	Resistor, Fixed Film 684Ω, 1/8W ±1/4%, TC ± 150 PPM	27690	M60-*
R40	801475	1	Resistor, Fixed Film 2.16K, 1/8W ±1/4%, TC ± 150 PPM	27690	M60-*
R41	801474	1	Resistor, Fixed Film 6.84K, 1/8W ±1/4%, TC ± 150 PPM	27690	M60-*
R42, R48, R45 R51	806156	4	Resistor, Fixed Film 10K, 1/4W ±2%	16299	C4-10K±2%
R43	806665	1	Resistor, Fixed Film 2.0K, 1/4W ±2%	16299	C4-2.0K±2%
R44, R50, R55	802232	3	Resistor, Fixed Comp. 1.5K, 1/4W ±5%	01121	CB1525
R46, R52	806667	2	Resistor, Fixed Film 300Ω, 1/4W ±2%	16299	C4-300Ω±2%
R47, R53	806723	2	Resistor, Variable 200Ω	80294	3389P200Ω
R49	806678	1	Resistor, Fixed Film 3.0K, 1/4W ±2%	16299	C4-3.0K±2%
R54	804297	1	Resistor, Fixed Comp. 2.2M, 1/4W ±5%	01121	CB2255
R56	205285	1	Resistor, Variable 250Ω (Ref Adj)	NAI	
R66, R73, R79, R127	801094	4	Resistor, Fixed Comp. 2K, 1/4W ±5%	01121	CB2025
R82	802192	1	Resistor, Fixed, Comp. 510Ω, 1/4W, ±5%	01121	CB5115
R83	801986	1	Resistor, Fixed, Comp. 100K, 1/4W, ±5%	01121	CB1045
R90	801638	1	Resistor, Fixed Comp. 47K, 1/4W ±5%	01121	CB4735
R91, R121	801636	2	Resistor, Fixed Comp. 20K, 1/4W ±5%	01121	CB2035
R92, R104, R105, R108	805612	4	Resistor, Fixed Film 5.11K, 1/4W ±1%	16299	C4-5.11K±1%
R93	807101	1	Resistor, Fixed Comp. 6.8Meg, 1/4W, ±5%	72136	CB 6833
R95, R111	807062	2	Resistor, Variable 100K	32997	3299W104
R96, R99	802191	2	Resistor, Fixed Comp. 2.7K, 1/4W ±5%	01121	CB2725
R98	205174	1	Resistor, Variable 10K (ϕ Trim)	NAI	
R100, R133	801988	2	Resistor, Fixed Comp. 15K, 1/4W, ±5%	01121	CB1535
R101	801393	1	Resistor, Fixed Comp. 24K, 1/4W ±5%	01121	CB2435
R102, R103	801395	2	Resistor, Fixed Comp. 6.2K, 1/4W ±5%	01121	CB6225
R106	806371	1	Resistor, Fixed Comp. 5.1Meg, 1/4W, ±5%	72136	CB5155
R107	805613	1	Resistor, Fixed Film 10.2K, 1/4W ±1%	16299	C4-10.2K±1%
R110	807112	1	Resistor, Fixed Film 43K, 1/4W ±2%	16299	C4-43K±2%
R113	806718	1	Resistor, Fixed Film 5.6K, 1/4W ±2%	16299	C4-5.6K±2%
R114	806684	1	Resistor, Fixed Film 2.7K, 1/4W ±2%	16299	C4-2.7K±2%
R116	806724	1	Resistor, Variable 10K	32997	3389P10K

*Add full description from "Description" column.

REPLACEMENT PARTS LIST (Continued)

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
R118	803784	1	Resistor, Fixed Comp. 10Ω, 1/4W ±5%	01121	CB1005
R119	802182	1	Resistor, Fixed Comp. 22K, 1/4W ±5%	01121	CB2235
R120	800785	1	Resistor, Fixed Comp. 1.2K, 2W ±5%	01121	HB1225
R128, R129, R131, R132, R134, R138, R140, R143	801006	8	Resistor, Fixed, Comp. 10K. 1/4W, ±5%	01121	CB1035
R130	801981	1	Resistor, Fixed, Comp. 100Ω, 1/4W ±5%	01121	CB1015
R135			Resistor, Fixed		
			Selected at Test From		
	804400		270K, 1/4W ±5%	01121	CB2745
	802085		300K, 1/4W ±5%	01121	CB3045
	803553		330K, 1/4W ±5%	01121	CB3345
	806241		360K, 1/2W ±5%	01121	CB3645
	801987		390K, 1/4W ±5%	01121	CB3945
R141	802226	1	Resistor, Fixed, Comp. 200Ω, 1/4W ±5%	01121	CB2015
R142	802904	1	Resistor, Fixed, Comp. 36K, 1/4W ±5%	01121	CB3635
S1	205224	1	Switch, Range	NAI	
S2	500846	1	Switch, Function	NAI	
S3	205284	1	Switch, Power (Ref. Int-Ext)	NAI	
S5	806796	1	Switch, (Input, Dir-Trans)	31918	2D15--BL4UGR
S6	806675	1	Switch, (115V - 230V)	79727	GF-326uL
T1	800536	1	Transformer, Reference	80223	0-16
T2	202819	1	Transformer, Power	NAI	
T3	201562	1	Signal Isolation Transformer (400 Hz and above)	NAI	
	782460	1	Signal Isolation Transformer (below 400 Hz)	NAI	
Z2, Z3, Z4, Z6, Z7	804749	5	Integrated Circuit MC1437L	04713	MC1437L
Z5, Z9	806347	2	Operational Amplifier, 301A	12040	LM301A
Z8	782957	1	Detector Module	NAI	
	201722	1	Knob, Medium Round	NAI	
	201719	2	Knob, Medium Pointer	NAI	
	201946	1	Knob, Conc. Adapt.	NAI	
	205298-1	1	Button (DIR)	NAI	
	205298-2	1	Button (TRANS)	NAI	
	500268	1	Phase Angle Dial Assy.	NAI	
	202561	1	Window Meter	NAI	
	800119	2	Binding Post, Red	81073	29-1R
	800120	3	Binding Post, Black	81073	29-1B
	800546	1	Binding Post	83330	137
	800339	1	Link, Shorting	24655	938C
XF1	800117	1	Fuseholder	75915	342001
	800502	1	Line Cord	70903	17408
XDS1	804544	1	Connector, Cartridge	72765	399-058
	802952	1	Speed Clip	72619	7538-XP51

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
ALTERNATE REFERENCE COMPONENTS - FREQUENCIES BELOW 400Hz					
R122, R123	801985	2	Resistor, Fixed, Comp. 51K, 1/4W ±5%	01121	CB5135
R130	801980	1	Resistor, Fixed, Comp. 51Ω, 1/4W ±5%*	01121	CB5105
T1	800050	1	Transformer**	80223	0-6
RESISTORS - FREQUENCIES 92Hz OR BELOW					
Note For all frequencies above 92Hz, use Band 7 resistors. Refer to page 6.8.					
R57, R69	806156	2	Resistor, Fixed, Film 10K, 1/4W ±2%	16299	C4-10K±2%
R58, R70	806680	2	Resistor, Fixed, Film 16K, 1/4W ±2%	16299	C4-16K±2%
R59, R71	806751	2	Resistor, Fixed, Film 56K, 1/4W ±2%	16299	C4-56K±2%
R60, R74	806752	2	Resistor, Fixed, Film 82K, 1/4W ±2%	16299	C4-82K±2%
R61			Resistor, Metal Film, Select at Test From		
	807558		910Ω, 1/4W, ±2%	16299	C4
	806667		1KΩ, 1/4W, ±2%	16299	C4
	803679		1.1KΩ, 1/4W, ±2%	16299	C4
R62, R72	802725	2	Resistor, Fixed, Comp. 43K, 1/4 ±5%	01121	CB4335
R63, R76	806753	2	Resistor, Fixed, Film 9.1K, 1/4W ±2%	16299	C4-9.1K±2%
R64, R77	806754	2	Resistor, Fixed, Film 27K, 1/4W ±2%	16299	C4-27K±2%
R65, R78	801721	2	Resistor, Fixed, Comp. 12K, 1/4W ±5%	01121	CB1235
R67, R80	806682	2	Resistor, Fixed, Film 24K, 1/4W ±2%	16299	C4-24K±2%
R68, R81	806755	2	Resistor, Fixed, Film 4.3K, 1/4W ±2%	16299	C4-4.3K±2%
R75	806663	1	Resistor, Fixed, Film 1K, 1/4W ±2%	16299	C4-1K±2%
BAND 1 30Hz to 39Hz					
C1, C4	806756	2	Capacitor, Fixed, Elec. 5.6uf, 20 VDC ±5%	06751	TS2K20565
C2, C3	806764	2	Capacitor, Fixed, Film .27uf, 80 VDC ±5%	06001	AE28R274J
C30, C45	806693	2	Capacitor, Fixed, Film .1 uf, 80 VDC ±5%	06001	AE17R104J
C31, C37, C39, C46, C52, C53	806762	6	Capacitor, Fixed, Film .39uf, 80 VDC ±5%	06001	AE36R394J
C32, C33, C48, C49	806763	4	Capacitor, Fixed, Film .33uf, 80 VDC ±5%	06001	AE29R334J
C36, C51	806686	2	Capacitor, Fixed, Film .47uf, 80 VDC ±5%	06001	AE36R474J
C64	806761	1	Capacitor, Fixed, Elec. .68 uf, 20 VDC ±5%	06751	TS1K20684
BAND 2 40Hz to 59Hz					
C1, C4	806757	2	Capacitor, Fixed, Elec. 3.3uf, 20 VDC ±5%	06751	TS2K20335
C2, C3	806694	2	Capacitor, Fixed, Film .15uf, 80 VDC ±5%	06001	AE22R154J
C30, C45	806691	2	Capacitor, Fixed, Film .068uf, 80 VDC ±5%	06001	AE17R683J
C31, C37, C39, C46, C52, C53	806764	6	Capacitor, Fixed, Film .27uf, 80 VDC ±5%	06001	AE28R274J
C32, C33, C48, C49	806695	4	Capacitor, Fixed, Film .22uf, 80 VDC ±5%	06001	AE22R224J
C36, C51	806763	2	Capacitor, Fixed, Film .33uf, 80 VDC ±5%	06001	AE29R334J
C64	806762	1	Capacitor, Fixed, Film .39uf, 80 VDC ±5%	06001	AE36R394J

*Replaces 801981
**Replaces 800536

REPLACEMENT PARTS LIST (Continued)

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
			BAND 3 60Hz to 92Hz		
C1, C4	806758	2	Capacitor, Fixed, Elec. 2.2uf, 20 VDC ±5%	06751	TS1K20225
C2, C3	806693	2	Capacitor, Fixed, Film .1uf, 80 VDC ±5%	06001	AE17R104J
C30, C45	806767	2	Capacitor, Fixed, Film .047uf, 80 VDC ±5%	06001	AE17R473J
C31, C37, C39, C46, C52, C53	806765	6	Capacitor, Fixed, Film .18uf, 80 VDC ±5%	06001	AE22R184J
C32, C33, C48, C49	806694	4	Capacitor, Fixed, Film .15uf, 80 VDC ±5%	06001	AE22R154J
C36, C51	806695	2	Capacitor, Fixed, Film .22uf, 80 VDC ±5%	06001	AE22R224J
C64	806764	1	Capacitor, Fixed, Film .27uf, 80 VDC ±5%	06001	AE28R274J
			BAND 4 93Hz to 137Hz		
C1, C4	806759	2	Capacitor, Fixed, Elec. 1.5uf, 20 VDC ±5%	06751	TS1K20155
C2, C3	806691	2	Capacitor, Fixed, Film .068uf, 80 VDC ±5%	06001	AE17R683J
C30, C45	806693	2	Capacitor, Fixed, Film .1uf, 80 VDC ±5%	06001	AE17R104J
C31, C37, C39, C46, C52, C53	806762	6	Capacitor, Fixed, Film .39uf, 80 VDC ±5%	06001	AE36R394J
C32, C33, C48, C49	806763	4	Capacitor, Fixed, Film .33uf, 80 VDC ±5%	06001	AE29R334J
C36, C51	806686	2	Capacitor, Fixed, Film .47uf, 80 VDC ±5%	06001	AE36R474J
C64	806765	1	Capacitor, Fixed, Film .18uf, 80 VDC ±5%	06001	AE22R184J
			BAND 5 138Hz to 204Hz		
C1, C4	806760	2	Capacitor, Fixed, Elec. 1.0uf, 20 VDC ±5%	06751	TS1K20105
C2, C3	806767	2	Capacitor, Fixed, Film .047uf, 80 VDC ±5%	06001	AE17R473J
C30, C45	806691	2	Capacitor, Fixed, Film .068uf, 80 VDC ±5%	06001	AE17R683J
C31, C37, C39, C46, C52, C53	806764	6	Capacitor, Fixed, Film .27uf, 80 VDC ±5%	06001	AE28R274J
C32, C33, C48, C49	806695	4	Capacitor, Fixed, Film .22uf, 80 VDC ±5%	06001	AE22R224J
C36, C51	806763	2	Capacitor, Fixed, Film .33uf, 80 VDC ±5%	06001	AE29R334J
C64	806688	1	Capacitor, Fixed, Film .12uf, 80 VDC ±5%	06001	AE22R124J
			BAND 6 205Hz to 309Hz		
C1, C4	806761	2	Capacitor, Fixed, Elec. .68uf, 20 VDC ±5%	06751	TS1K20684
C2, C3	806689	2	Capacitor, Fixed, Film .033uf, 80 VDC ±5%	06001	AE15R333J
C30, C45	806767	2	Capacitor, Fixed, Film .047uf, 80 VDC ±5%	06001	AE17R473J
C31, C37, C39, C46, C52, C53	806765	6	Capacitor, Fixed, Film .18uf, 80 VDC ±5%	06001	AE22R184J
C32, C33, C48, C49	806694	4	Capacitor, Fixed, Film .15uf, 80 VDC ±5%	06001	AE22R154J
C36, C51	806695	2	Capacitor, Fixed, Film .22uf, 80 VDC ±5%	06001	AE22R224J
C64	806766	1	Capacitor, Fixed, Film .82uf, 80 VDC ±5%	06001	AE17R823J

REPLACEMENT PARTS LIST (Continued)

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
			BAND 7 310Hz to 464Hz		
R57, R69	806678	2	Resistor, Fixed, Film 3K, 1/4W ±2%	16299	C4-3K±2%
R58, R70	806679	2	Resistor, Fixed, Film 5.1K, 1/4W ±2%	16299	C4-5.1K±2%
R59, R71	806680	2	Resistor, Fixed, Film 16K, 1/4W ±2%	16299	C4-16K±2%
R60, R74	807122	2	Resistor, Fixed, Film 22K, 1/4W ±2%	16299	C4-22K±2%
R61			Resistor, Metal Film, Select at Test From		
	807558		270 Ω, 1/4W, ±2%	16299	C4
	806667		300 Ω, 1/4W, ±2%	16299	C4
	803679		330 Ω, 1/4W, ±2%	16299	C07
R63, R76	805684	2	Resistor, Fixed, Film 2.7K, 1/4W ±2%	16299	C4-2.7K±2%
R64, R77	806685	2	Resistor, Fixed, Film 8.2K, 1/4W ±2%	16299	C4-8.2K±2%
R67, R80	805639	2	Resistor, Fixed, Film 7.5K, 1/4W ±2%	16299	NA60-7.5K±2%
R68, R81	805640	2	Resistor, Fixed, Film 1.3K, 1/4W ±2%	16299	NA60-1.3K±2%
R62, R72	801721	2	Resistor, Fixed, Comp. 12K, 1/4W ±5%	01121	CB1235
R65, R78	801398	2	Resistor, Fixed, Comp. 3.6K, 1/4W ±5%	01121	CB3625
R75	806667	1	Resistor, Fixed, Film 300Ω, 1/4W ±2%	16299	C4-300Ω±2%
C30, C45	806689	2	Capacitor, Fixed, Film .033uf, 80 VDC ±5%	06001	AE15R333J
C64	806720	1	Capacitor, Fixed, Film .056uf, 80 VDC ±5%	06001	AE17R563J
C36, C51	806694	2	Capacitor, Fixed, Film .15uf, 80 VDC, ±5%	06001	AE22R154J
C32, C33, C48, C49	806693	4	Capacitor, Fixed, Film .1uf, 80 VDC ±5%	06001	AE17R104J
C1, C4	806686	2	Capacitor, Fixed, Film .47uf, 80 VDC, ±5%	06001	AE36R474J
C2, C3	806687	2	Capacitor, Fixed, Film .022uf, 80 VDC, ±5%	06001	AE15R223J
C31, C46, C52, C53, C37, C39	806688	6	Capacitor, Fixed, Film .12uf, 80 VDC, ±5%	06001	AE22R124J
			BAND 8 465Hz to 699Hz		
C1, C4	806763	2	Capacitor, Fixed, Film .33uf, 80 VDC ±5%	06001	AE29R334J
C2, C3	806771	2	Capacitor, Fixed, Film .015uf, 80 VDC ±5%	06001	AE15R153J
C30, C45	806687	2	Capacitor, Fixed, Film .022uf, 80 VDC ±5%	06001	AE15R223J
C31, C37, C39, C46, C52, C53	806766	6	Capacitor, Fixed, Film .082uf, 80 VDC ±5%	06001	AE17R823J
C32, C33, C48, C49	806691	4	Capacitor, Fixed, Film .068uf, 80 VDC ±5%	06001	AE17R683J
C36, C51	806693	2	Capacitor, Fixed, Film .1uf, 80 VDC ±5%	06001	AE17R104J
C64	806768	1	Capacitor, Fixed, Film .039uf, 80 VDC ±5%	06001	AE17R393J
			BAND 9 700Hz to 1.05Hz		
C1,C4	806695	2	Capacitor, Fixed, Film .22uf, 80 VDC ±5%	06001	AE22R224J
C2, C3	806690	2	Capacitor, Fixed, Film .01uf, 80 VDC ±5%	06001	AE13R103J
C30, C45	806771	2	Capacitor, Fixed, Film .015uf, 80 VDC ±5%	06001	AE15R153J
C31, C37, C39, C46, C52, C53	806720	6	Capacitor, Fixed, Film .056uf, 80 VDC ±5%	06001	AE17R563J
C32, C33, C48, C49	806767	4	Capacitor, Fixed, Film .047uf, 80 VDC ±5%	06001	AE17R473J
C36, C51	806691	2	Capacitor, Fixed, Film .068uf, 80 VDC ±5%	06001	AE17R683J
C64	806769	1	Capacitor, Fixed, Film .027uf, 80 VDC ±5%	06001	AE15R273J

REPLACEMENT PARTS LIST (Continued)

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
			BAND 10 1.06KHz to 1.57KHz		
C1, C4	806694	2	Capacitor, Fixed, Film .15uf, 80 VDC ±5%	06001	AE22R154J
C2, C3	806774	2	Capacitor, Fixed, Film .0068uf, 80 VDC ±5%	06001	AE13R682J
C30, C45	806690	2	Capacitor, Fixed, Film .01uf, 80 VDC ±5%	06001	AE13R103J
C31, C37, C39, C46, C52, C53	806689	6	Capacitor, Fixed, Film .033uf, 80 VDC ±5%	06001	AE15R333J
C32, C33, C48, C49	806769	4	Capacitor, Fixed, Film .027uf, 80VDC ±5%	06001	AE15R273J
C36, C51	806767	2	Capacitor, Fixed, Film .047uf, 80 VDC ±5%	06001	AE17R473J
C64	806770	1	Capacitor, Fixed, Film .018uf, 80 VDC ±5%	06001	AE15R183J
			BAND 11 1.58KHz to 2.36KHz		
C1, C4	806693	2	Capacitor, Fixed, Film .10uf, 80 VDC ±5%	06001	AE17R104J
C2, C3	806776	2	Capacitor, Fixed, Film .0047uf, 80 VDC ±5%	06001	AE12R472J
C30, C45	806774	2	Capacitor, Fixed, Film .0068uf, 80 VDC ±5%	06001	AE13R682J
C31, C37, C39, C46, C52, C53	806687	6	Capacitor, Fixed, Film .022uf, 80 VDC ±5%	06001	AE15R223J
C32, C33, C48, C49	806770	4	Capacitor, Fixed, Film .018uf, 80 VDC ±5%	06001	AE15R183J
C36, C51	806769	2	Capacitor, Fixed, Film .027uf, 80 VDC ±5%	06001	AE15R273J
C64	806773	1	Capacitor, Fixed, Film .0082uf, 80 VDC ±5%	06001	AE13R822J
			BAND 12 2.37KHz to 3.55KHz		
C1, C4	806691	2	Capacitor, Fixed, Film .068uf, 80 VDC ±5%	06001	AE17R683J
C2, C3	806779	2	Capacitor, Fixed, Film .0027uf, 80 VDC ±5%	06001	AE12R272J
C30, C45	806776	2	Capacitor, Fixed, Film .0047uf, 80 VDC ±5%	06001	AE12R472J
C31, C37, C39, C46, C52, C53	806771	6	Capacitor, Fixed, Film .015uf, 80 VDC ±5%	06001	AE15R153J
C32, C33, C48, C49	806772	4	Capacitor, Fixed, Film .012uf, 80 VDC ±5%	06001	AE15R123J
C36, C51	806770	2	Capacitor, Fixed, Film .018uf, 80 VDC ±5%	06001	AE15R183J
C64	806776	1	Capacitor, Fixed, Film .0047uf, 80 VDC ±5%	06001	AE12R472J
			BAND 13 3.56KHz to 5.34KHz		
C1, C4	806768	2	Capacitor, Fixed, Film .039uf, 80 VDC ±5%	06001	AE17R393J
C2, C3	806781	2	Capacitor, Fixed, Film .0018uf, 80 VDC ±5%	06001	AE12R182J
C30, C45	806781	2	Capacitor, Fixed, Film .0018uf, 80 VDC ±5%	06001	AE12R182J
C31, C37, C39, C46, C52, C53	806690	6	Capacitor, Fixed, Film .01uf, 80 VDC ±5%	06001	AE13R103J
C32, C33, C48, C49	806773	4	Capacitor, Fixed, Film .0082uf, 80 VDC ±5%	06001	AE13R822J
C36, C51	806772	2	Capacitor, Fixed, Film .012uf, 80 VDC ±5%	06001	AE15R123J
C64	806778	1	Capacitor, Fixed, Film .0033uf, 80 VDC ±5%	06001	AE12R332J

REPLACEMENT PARTS LIST (Continued)

DESIGNATION	NAI PART NO.	TOTAL QTY.	DESCRIPTION	CODE IDENT.	MFR. PART NO.
BAND 14 5.35KHz to 7.9KHz					
C1, C4	806769	2	Capacitor, Fixed, Film .027uf, 80 VDC ±5%	06001	AE15R273J
C2, C3	806783	2	Capacitor, Fixed, Film .012uf, 80 VDC ±5%	06001	AE12R122J
C30, C45	806781	2	Capacitor, Fixed, Film .0018uf, 80 VDC ±5%	06001	AE12R182J
C31, C37, C39, C46, C52, C53	806774	6	Capacitor, Fixed, Film .0068uf, 80 VDC ±5%	06001	AE13R682J
C32, C33, C48, C49	806774	4	Capacitor, Fixed, Film .0068uf, 80 VDC ±5%	06001	AE13R682J
C36, C51	806773	2	Capacitor, Fixed, Film .0082uf, 80 VDC ±5%	06001	AE13R822J
C64	806780	1	Capacitor, Fixed, Film .0022uf, 80 VDC ±5%	06001	AE12R223J
BAND 15 8KHZ to 10KHz					
C1, C4	806770	2	Capacitor, Fixed, Film .018uf, 80 VDC ±5%	06001	AE15R183J
C2, C3	802333	2	Capacitor, Fixed, Mica 910pf, 500V ±5%	72136	DM-19-911J
C30, C45	806783	2	Capacitor, Fixed, Film .0012uf, 80 VDC ±5%	06001	AE12R122J
C31, C37, C39, C46, C52, C53	806776	6	Capacitor, Fixed, Film .0047uf, 80 VDC ±5%	06001	AE12R472J
C32, C33, C48, C49	806777	4	Capacitor, Fixed, Film .0039uf, 80 VDC ±5%	06001	AE12R392J
C36, C51	806775	2	Capacitor, Fixed, Film .0056uf, 80 VDC ±5%	06001	AE13R562J
C64	806782	1	Capacitor, Fixed, Film .0015uf, 80 VDC ±5%	06001	AE12R152J

SECTION VII

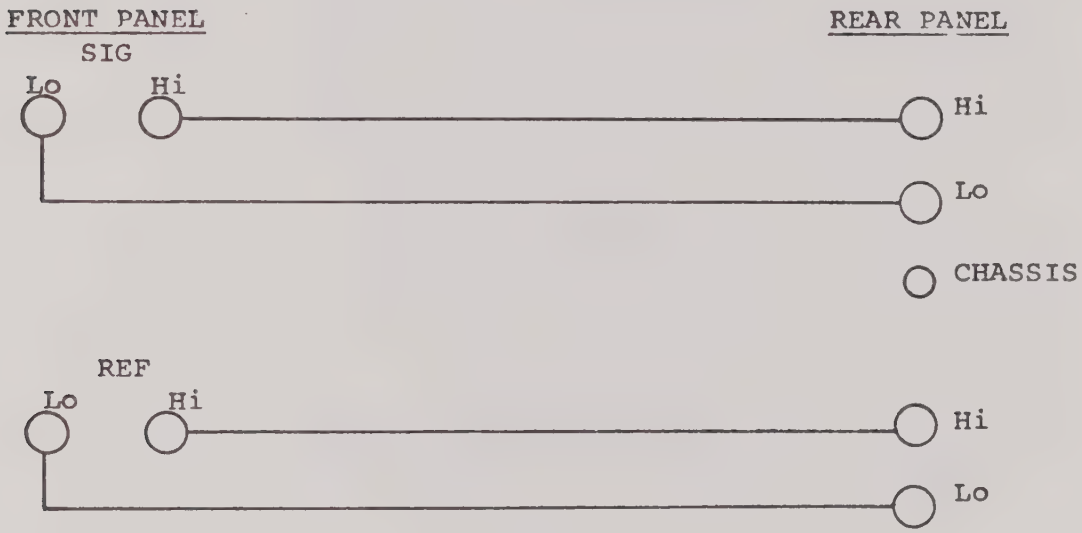
VM 213

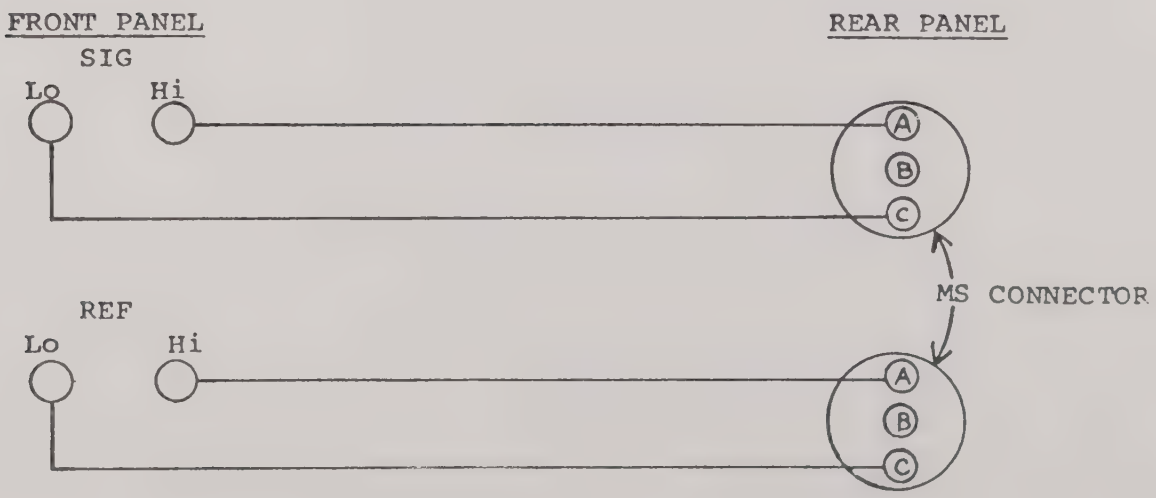
STANDARD OPTIONS
(FACTORY INSTALLED)

BACK PANEL OPTIONS

MODELS 213B AND 213C

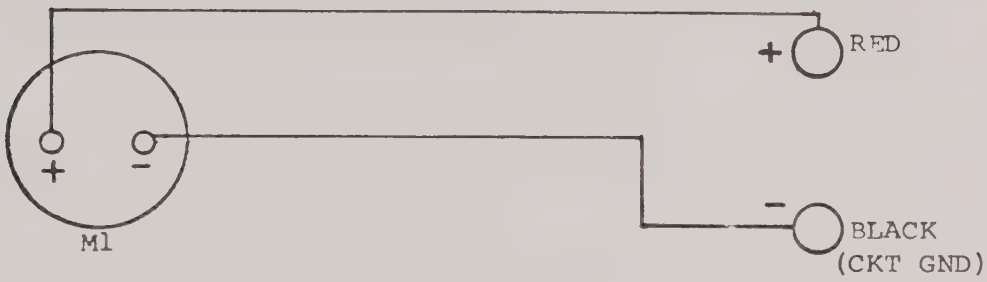
Signal and Reference input terminals located on the fron' and rear of instrument are connected as shown.





BACK PANEL OPTIONS

The Meter (M1) terminals are connected to the five-way binding posts at the rear of the instrument as shown below



CAUTION

Both of these points are floating with respect to system ground and use of this DC level requires a device whose input is balanced to ground, including common-mode rejection. In addition, the unit's calibration should be checked for no loading effects.

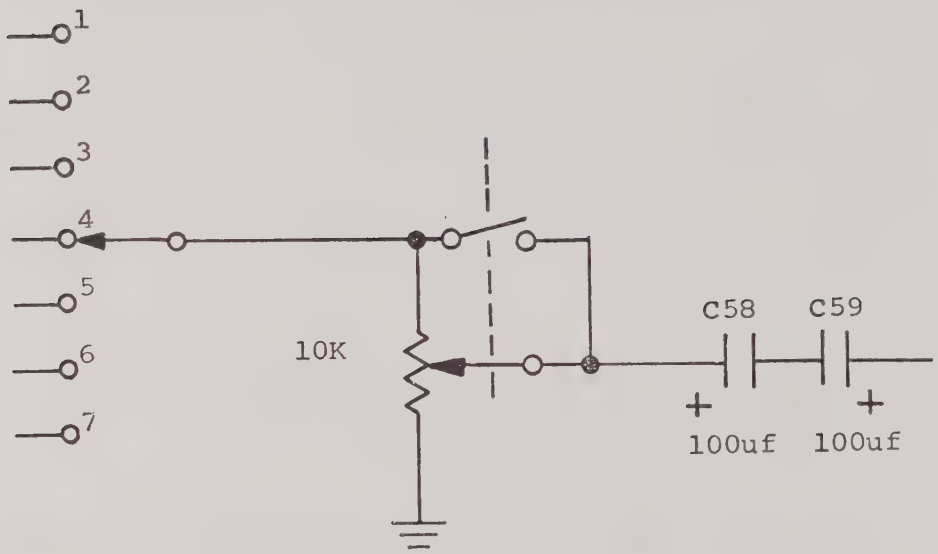
The nominal full scale output voltage will be 20 to 30 millivolts. This output level may be checked, observing the above precautions. The output impedance of these terminals is normally 1.5K.

PARTS LIST

Binding Post Red	800119
Binding Post Black	800120
Connector MS3102A-10SL-3P	800669

FULL SCALE ADJUST OPTION

S2-E



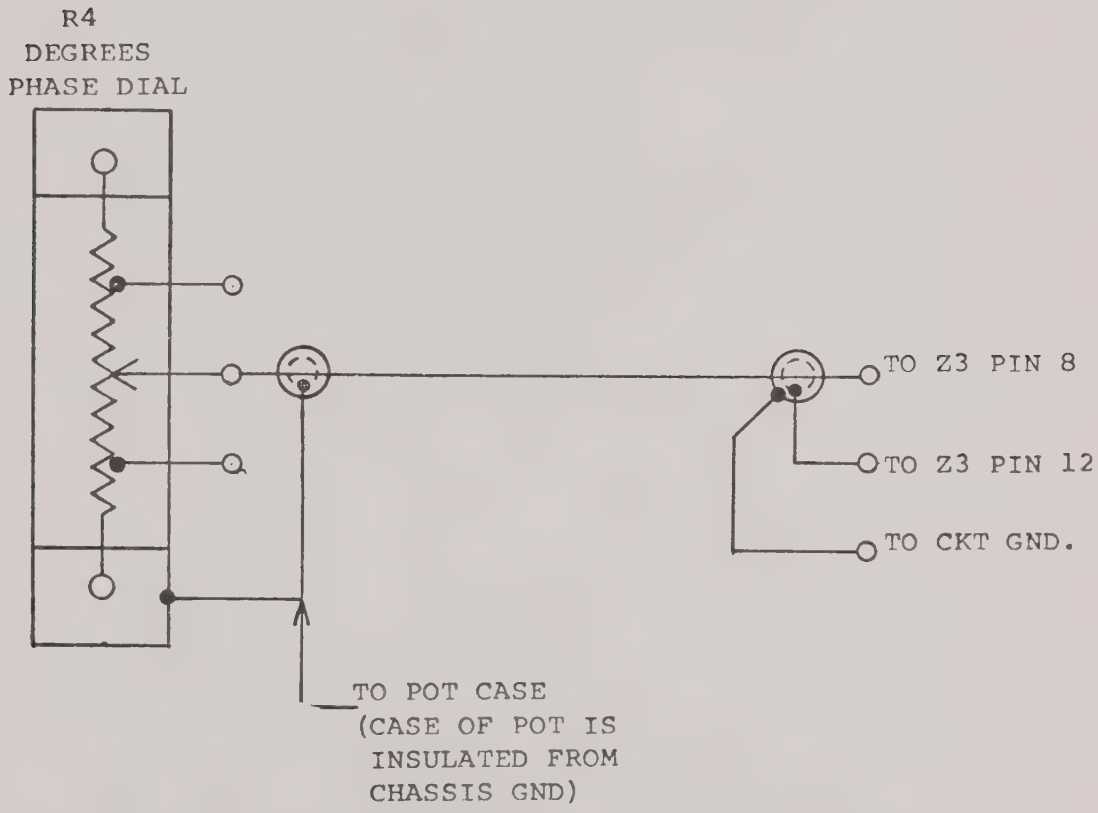
Switch is closed in full CW position

PARTS LIST

1 Knob	201720
1 Potentiometer-Switch 10K	802589

WIRING OF DEGREES PHASE DIAL

FOR FREQUENCIES 2KHz THRU 10KHZ



FRONT PANEL DRESS KIT OPTION

Front Panel Dress Kit	500579
Bezel	202167-2
Handle Assy L.H.	500483-2
Handle Assy R.H.	500482-2

SECTION VIII

APPENDIX

APPLICATION NOTES

FOR

NORTH ATLANTIC

PHASE ANGLE VOLTMETER

The North Atlantic Industries Phase Angle Voltmeter is a truly unique, multifunctional instrument which will function as a sensitive voltmeter, a phase angle meter, a meter measuring in-phase signals (E cos θ), and quadrature signals (E sin θ), a phase sensitive null indicator, an impedance meter, and a power factor meter.

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8.1 INTRODUCTION.

The following notes will acquaint the user of the Phase Angle Voltmeter with the many ways in whch these versatile instruments can be used.

By virtue of the instrument's ability to measure the two basic characteristics of any signal; namely, magnitude and phase angle, measurements are now possible which previously either required extensive associated equipment or could not be made at all.

An input signal is first attenuated by the range multiplier. The high gain amplifier drives a phase sensitive detector which in turn drives the indicating meter. A reference signal is also amplified and its phase angle shifted by the calibrated phase shifter. This signal driving the phase sensitive detector results in the phase angle characteristics shown in Figures (5) and (6).

The sections to follow describe the many ways in which this instrument is being used. Block Diagrams illustrate typical measuring set ups.

8.2 GENERAL NOTES ON GROUNDING TECHNIQUES.

Successful measurement with any high input impedance voltmeter is dependent upon the elimination of all unwanted or extraneous signals from the measurement circuit.

The most common sources for extraneous signals are the following:

A. Internal noise

B. Electrostatic pickup

C. Inductive pickup

D. Common ground runs

Internal noise has been minimized by design and successful measurements can be made in circuits with impedances as high as 1.0 megohms.

Electrostatic pickup, frequently a problem in high impedance circuits, is easily eliminated by shielded cable or

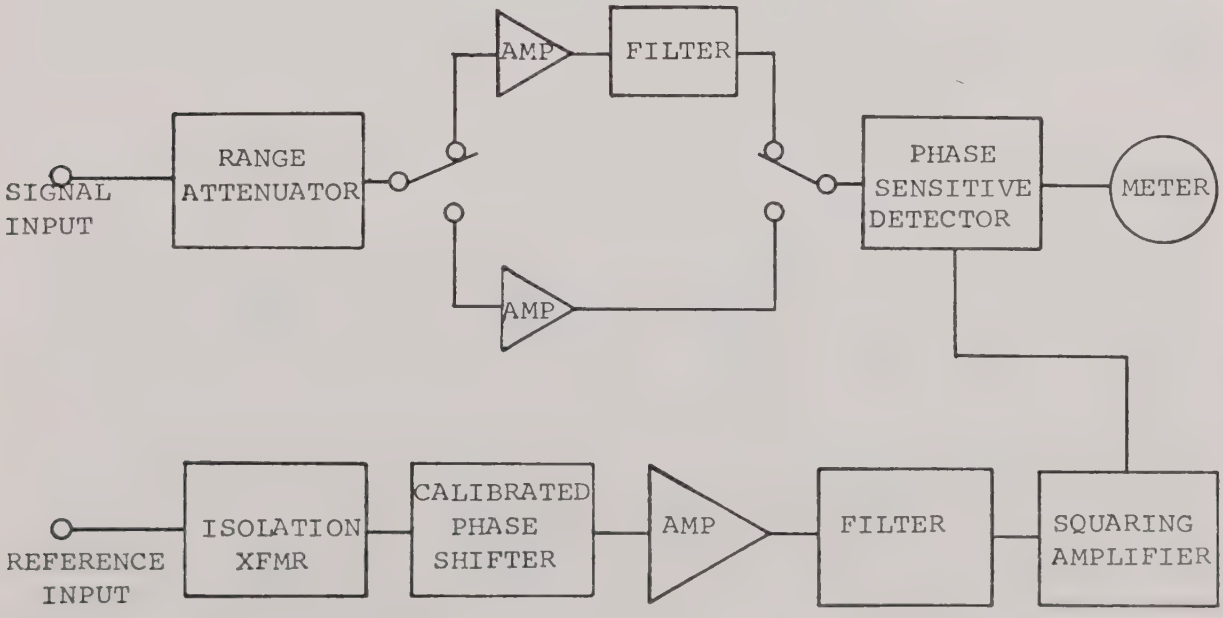


Figure 1 Phase Angle Voltmeter, Block Diagram

twisted leads one of which is at ground potential. Care must be taken, however, to avoid loading the signal source by the cable capacitance.

Inductive pickup is generally less often encountered than electrostatic pickup and possibly for that reason, methods for minimizing it are not frequently employed. Both twisted and shielded leads are effective in reducing this form of pickup because they minimize the effective area through which extraneous electromagnetic flux can pass. This is true in the case of a shielded lead, only if the shield, for example, is the return circuit for the signal.

Inductive pickup in ground leads can and does occur with multiple point grounding systems. The effect of these ground loops frequently can be reduced by bundling cables together, again so as to minimize loop areas. A better method is to eliminate the ground loops altogether especially those in the signal system or that portion of a circuit where a measurement is being made. Figure (2) shows several workable methods for using the voltmeter as a phase sensitive null detector when making transformation measurements. All methods can be made to work by minimizing stray fields and bundling cables together. However, Figure (2A) is the most advantageous arrangement and is not at all critical to lead runs. Figures (2B) and (2C) both have loops which can be potential trouble spots. Note also that grounds other than those shown in Figure (2) can exist due to chassis contact, line cord ground, and reference grounds. All must be considered when setting up the measuring system.

Common ground runs are sources of extraneous signals by virtue of voltage drops in the voltmeter input which arise from ground current other than the signal ground current. Figure (3) is a sketch of a typical arrangement wherein the power ground lead is in part that of the shield on the signal input. A portion of the load current as well as power supply leakage current to ground go through the voltmeter input cable. The voltage drop in the length of common ground is measured in addition to the signal.

Figure (3) also illustrates the internal grounding arrangement. The fact that there are four places in which a ground can be made could mean that isolation transformers are required somewhere in the measuring circuit.

8.3 PHASE CHARACTERISTIC.

8.3.1 RESPONSE TO HARMONICS.

The response of the Phase Angle Voltmeter to the fundamental frequency is given by:

(1) $E_{meter} = E_{rms} \times \cos\theta$

where E_{meter} = voltage read on the meter
E_{rms} = rms value of the input sine wave
θ = angle between the reference and signal input (Phase shifter at zero degrees)

Response to even order harmonics is theoretically zero, while odd harmonic response varies inversely with the order of the harmonic.

For example, for the 3rd harmonic equation (1) becomes:

(2) $$E_{meter} = \frac{E_{rms\ (3rd\ harmonic)} \times \cos\theta'}{3}$$

where θ' is the phase angle of the 3rd harmonic with respect to the reference.

Actually response to harmonics departs from equation (2) for a number of reasons. Since calibration of the instrument is at the fundamental frequency, measurements at frequencies other than the fundamental frequency will be somewhat in error.

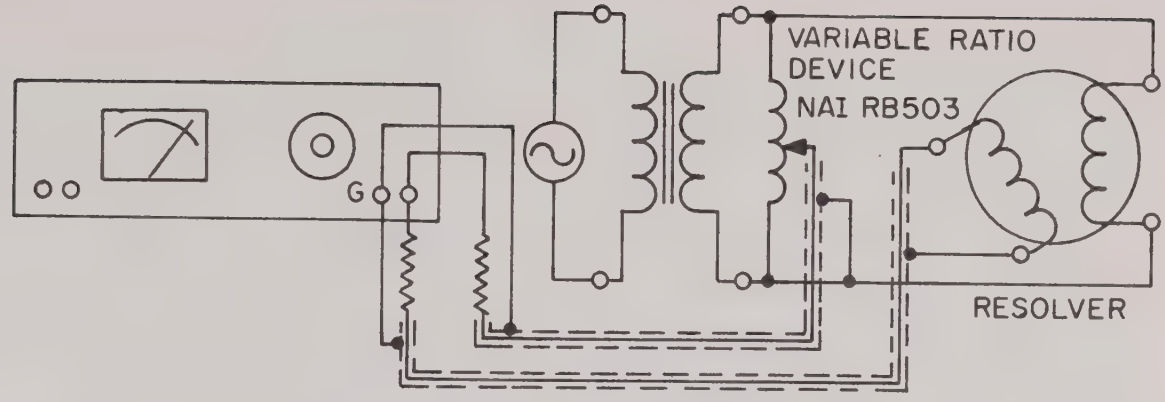
For instruments having selective filters in the signal and reference channels, harmonic response will in all cases be more than 55DB down. Table I shows typical measured responses. The values shown with filters actually are the sum of the column I data and the filter characteristic.

Table I

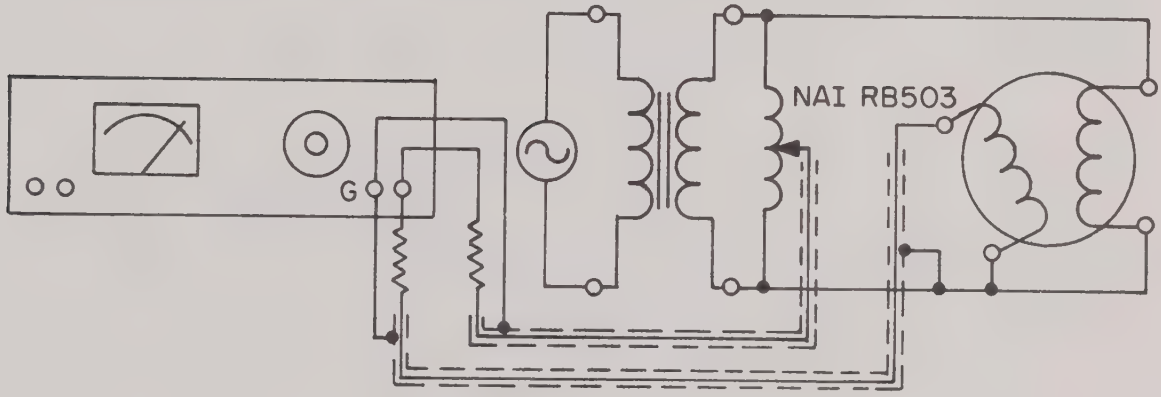
FUND (400cps)	No Signal Filter 0DB	With Signal Filter 0DB
2nd Har.	-55DB	-55DB
3rd Har.	-9.5DB	-55DB
4th Har.	-55DB	-55DB
5th Har.	-14DB	-55DB

8.3.2 ACCURATE PHASE MEASUREMENTS.

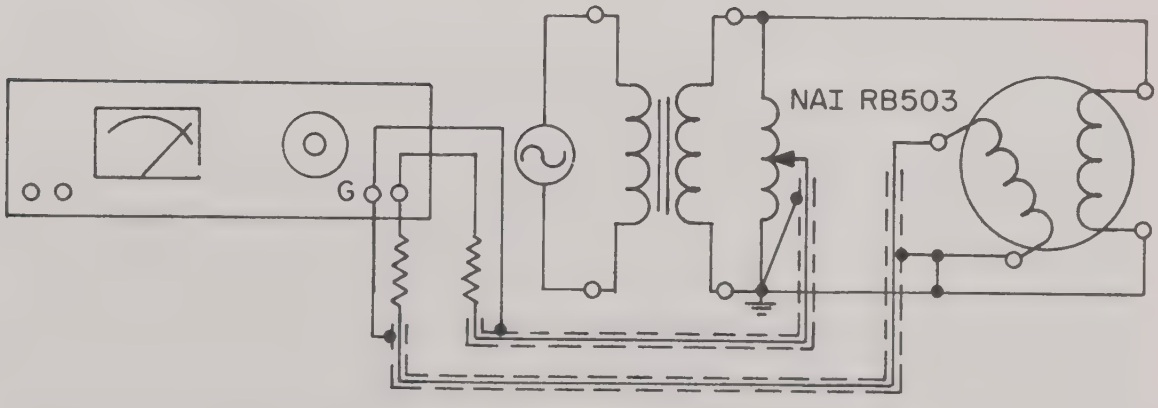
Measurements of phase angle using equation (1) are easily accomplished with good accuracy using the setup shown in Figure (4). The actual phase characteristic used in the measurement is E sin θ for purpose of convenience. The procedure is to adjust accurately the $\theta = 90$ deg. and the $\theta = 0$ deg. point. Measurement than will be a voltage which can be directly translated into degrees using the curves of Figures (5) and (6).



(a)–GOOD, NO LOOPS



(b)–ONE LOOP, PICK-UP POSSIBLE



(c)–POOR–ONE SIGNAL LOOP AND ONE GROUND LOOP

Figure 2. Ratiometer with Parallel Summing

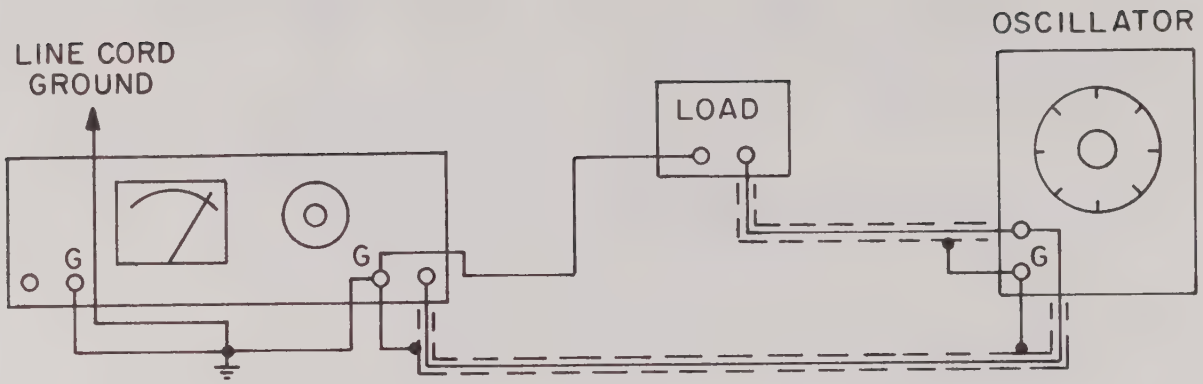


Figure 3. Internal Grounding

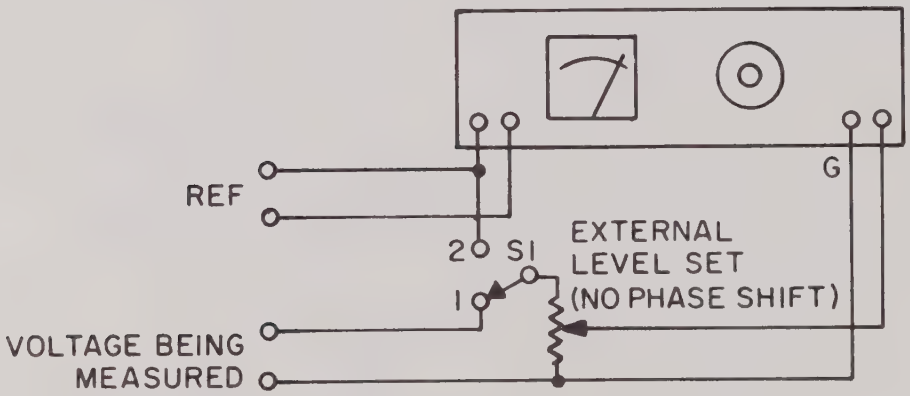


Figure 4. Phase Angle Measurement

The step-by step procedure is:

A. Set reference level to red line value.

B. With meter in "STD VTVM" position and external switch S1 in position 1, select a convenient range and adjust the signal level for full scale deflection. This will insure on-scale readings. (NOTE: Any external level set should be sufficiently low in resistance so as not to introduce phase shift error.

C. Switch the reference into the signal channel by switching S1 to position 2 and adjust using the same external level control for full scale deflection. Switch the instrument to the "PHASE ANGLE VTVM" function and adjust the phase shift dial for zero meter reading. This establishes the $\theta = 0$ deg. point or quadrature null point.

Note

FOR MAXIMUM ACCURACY, THIS POINT SHOULD BE RESET WHENEVER THE SCALE IS CHANGED.

D. Return the switch S1 to the signal input and readjust the full scale level with the instrument set as "STD VTVM". This establishes the θ = 90 deg. point (E maximum).

E. Switch back to the "PHASE ANGLE VTVM" position used in (3) above and read the meter. Enter the curves of Figure (5) or (6) to read degrees.

Any full scale range in degrees can be used even down to -6 deg. - 0 - +6 deg., depending upon the full scale limits. For example, if the full scale 90 degree point is set on the 1.0 volt scale and the zero point on the 0.3 volt scale, then the 0.3 volt scale will cover a range of -17.4 deg. - 0 - +17.4 deg. Table II summarizes typical setups and Figures (5) and (6) show curves which can easily be used to convert voltage measurements to degrees. These curves are actually arc sine functions. The angle can also be derived by direct computation from the voltage readings.

Errors in using this type of measurement will be a function of the scale used and the angle. In addition, for large ratios of maximum voltage to full scale values being used, saturation for a portion of each cycle can occur and will result in a small scale error. Obviously, this condition is a function of reference level and for that reason, a level of twice the red line value is recommended when using this technique.

High accuracy Phase Angle Measurements to better than .01° can be made using the alternate methods discussed in Small Angle Measurements, paragraph 8.8.7.

8.4 PHASE ANGLE MEASUREMENTS USING CALIBRATED PHASE SHIFTER.

The built-in, calibrated phase shifter can be used to measure phase angle directly simply by shifting the reference by an amount equal to the phase angle being measured so as to produce a maximum meter reading in accordance with equation (1). Precise determination of the maximum point is difficult due to the zero slope of the phase characteristic at θ = 0 deg. To avoid this difficulty, the instrument is equipped with four scales 90 degrees apart. Thus, by simply switching the reference 90 degrees, the phase shifter dial can be readily set to a zero point on the meter and then by switching back to the original quadrant the unknown phase angle can be read.

This procedure allows the measurement of phase angles from 0 to 360 degrees. Ambiguity which exists for two quadrants is easily removed by adding 180 degrees to the dial reading if a negative maximum (meter deflection to the LEFT) is used for the measurement. For positive maximums (meter deflections to the RIGHT) the dial scales apply directly.

Table II

Maximum Voltage	Scale for Measuring Degrees	Full Scale Overload Ratio	Degree Range	Max. Error 3%	Figure
1.0	1.0	1:1	90	2.7 deg	5
1.0	.3	3.3:1	17.4	.52	6
1.0	.1	10:1	5.7	.2	5
1.5	1.0	1.5:1	41.8	1.3	5
1.5	.3	5:1	11.5	.33	6

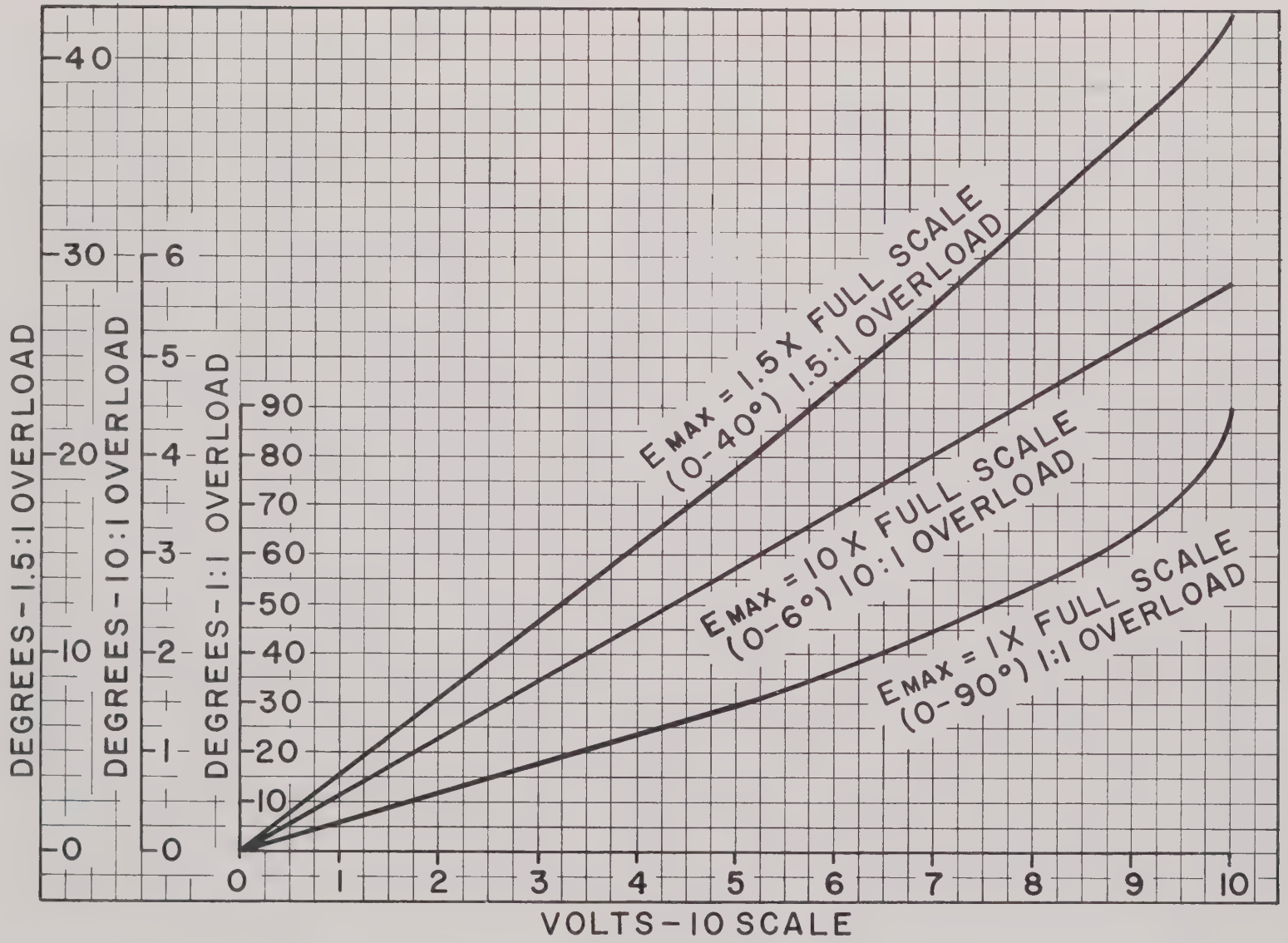

DEGREES – 1.5:1 OVERLOAD
DEGREES – 10:1 OVERLOAD
DEGREES – 1:1 OVERLOAD
VOLTS – 10 SCALE
E MAX = 1.5 X FULL SCALE (0-40°) 1.5:1 OVERLOAD
E MAX = 10 X FULL SCALE (0-6°) 10:1 OVERLOAD
E MAX = 1 X FULL SCALE (0-90°) 1:1 OVERLOAD

Figure 5 Phase Angle Voltmeter Characteristic

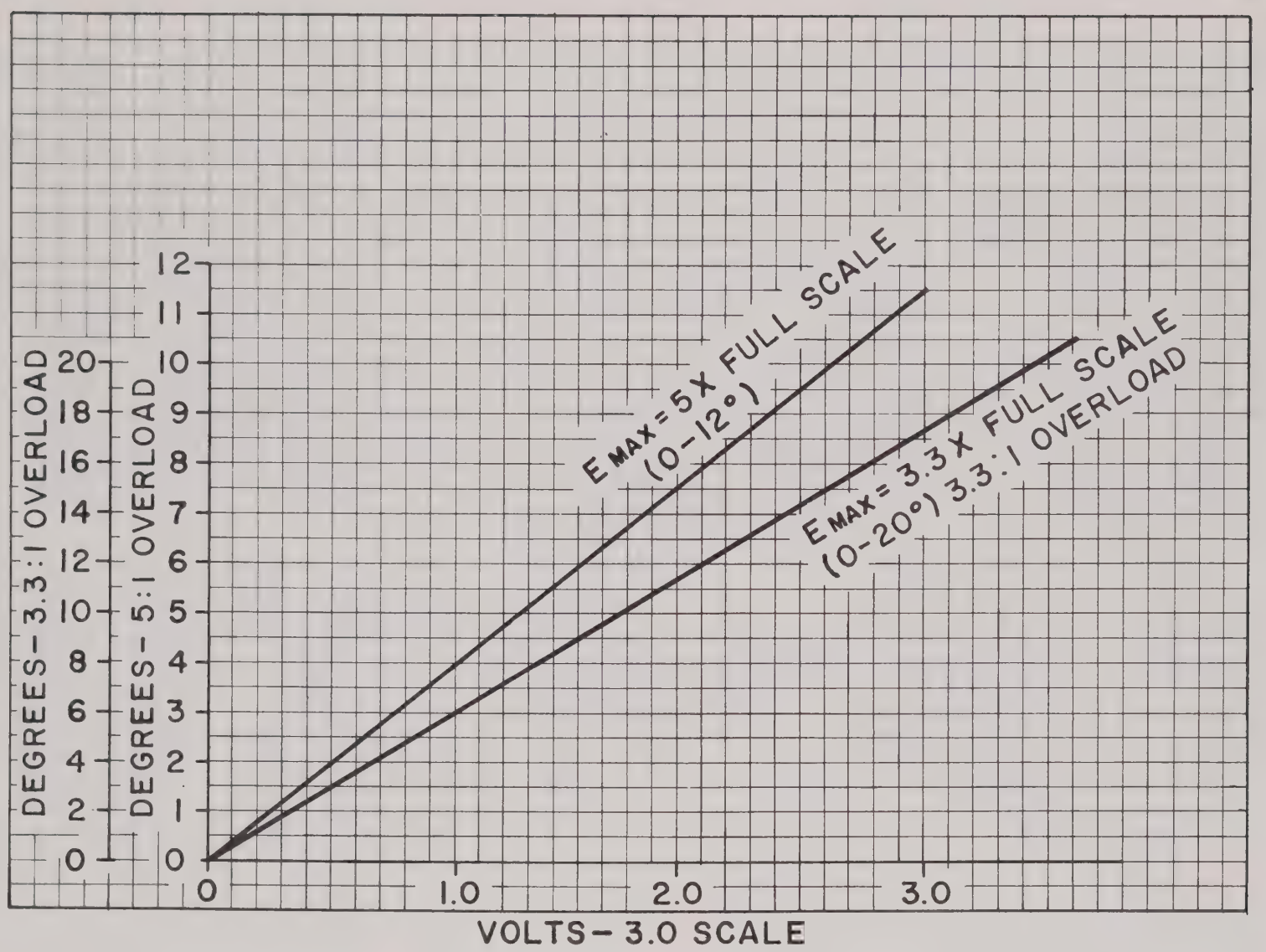


Figure 6 Phase Angle Voltmeter Characteristic

8.5 MEASUREMENT OF QUADRATURE AND IN-PHASE COMPONENTS OF A SIGNAL.

The quadrature and in-phase components of a signal are defined in accordance with the diagram of Figure (7) as:

In-phase component = E cos θ
Quadrature component = E sin θ

Measurement of the in-phase component is made by placing the Phase Angle Dial at zero degrees and reading the meter directly. This voltage will be E cos θ. (Function Selector must be in one of the PHASE ANGLE VTVM positions). By switching the Function Selector to an adjacent quadrant, the reference is shifted 90 degrees and the meter now reads the quadrature component of voltage E sin θ. For the greatest accuracy in this type of measurement, the null or 90 degree point should be calibrated on the scale in which the voltage component is to be read. See the section under PHASE CHARACTERISTIC for a description of this type of adjustment.

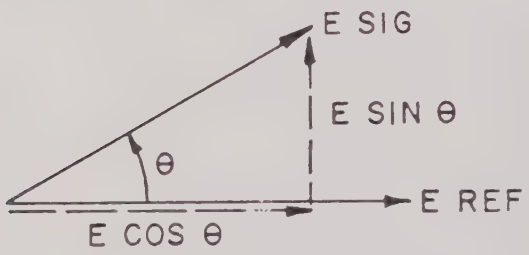


Figure 7

8.6 MEASUREMENT OF POWER FACTOR AND IMPEDANCE ANGLE.

Both power factor and impedance angle are defined as the angle which a current vector makes with the voltage reference. This measurement is conveniently accomplished by means of the set up shown in Figure (8). The angle is measured as previously discussed.

8.7 IMPEDANCE MAGNITUDE.

The magnitude of any impedance is measured by using the "STD VTVM" portion of the instrument. Figure (9) illustrates the manner in which the measurements can be made.

Using Table III as a guide, a precision ($\pm$ 1%) resistor of convenient size is selected for Rs. With S1 in position 1 for measuring current, adjust the scale set potentiometer to read full scale voltage on any 10 scale. Note the actual voltage value. Switch S1 to position 2 for measuring /Z/ and read the meter. This reading will be the impedance magnitude expressed in units of kilohms, ohms, hundreds of ohms, milliohms, etc. depending upon the value of Rs series resistance used per Table III and when divided by the current measurement noted above.

EXAMPLE:

Load impedance = 470K
Rs = 1K
E line = 115 volts

With S1 in position 1 set the level using R2 to a convenient full scale of 10. This might be 0.1 volts. Switching then to position S2 will produce a meter deflection of 47K on the 100K scale (100 volts scale is now 100K per Table III). Dividing this by the current scale of 0.1 will yield 470K. Since the current factor is always set at a multiple of 10, this last correction is simple to accomplish.

Table III

Series Resistor	Scale 1V equals	Current Factor
10K	10K	1/volts
1K	1K	1/volts
100Ω	100Ω	1/volts
10Ω	10Ω	1/volts
1Ω	1Ω	1/volts

8.7.1 MEASUREMENT OF AC RESISTANCE AND REACTANCE

By using the circuit of Figure (9) the real and imaginary components of the impedance can also be measured directly by using the current as a reference and measuring the in-phase and quadrature of the signal measured with the switch in position 2. The in-phase component will be the AC Resistance and the quadrature component will be the reactance with the sign determined as positive for a right hand meter deflection and negative for a left hand deflection.

The following series of block diagrams will illustrate how this instrument can be applied to some of the specific applications noted earlier.

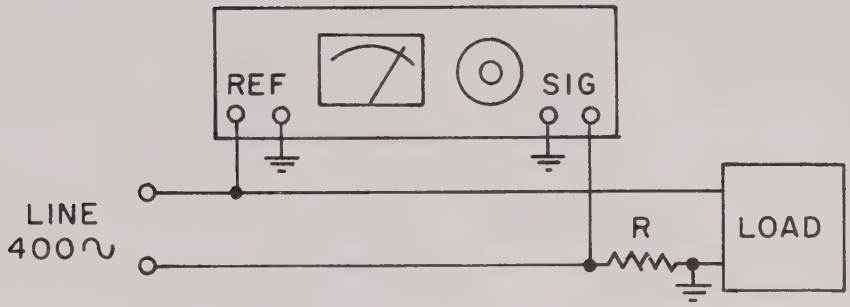


Figure 8. Power Factor and Impedance Angle Measurement

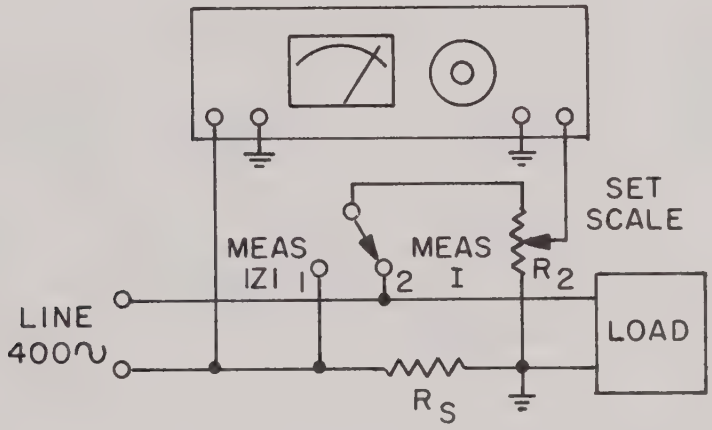


Figure 9. Impedance Magnitude Measurement

8.8 APPLICATIONS.

8.8.1 PRECISION RATIOMETER.

In many analog computer systems the process of multiplication, division, addition, and subtraction is accomplished using precision potentiometers, or resistors. Those applications involving extremes of precision must be concerned with the distributed capacitance of the circuit element. Ordinary nulling system, for example, will not permit the manufacture of very precise resistors because of the errors masked by quadrature signals. The circuit of Figure (10) permits precise zeroing of pots or matching and calibration of resistors and potentiometers independent of stray capacitances, or harmonics in the signal source. Two isolation transformers are actually not necessary. If the source is to be isolated then an inexpensive transformer can be used. If the outputs are to be isolated than a low capacitance transformer such as North Atlantic's T-110 should be used. An alternate arrangement would be the circuit of Figure (11), which uses a summing network.

8.8.2 TRANSDUCER NULLING.

Applications involving transducers, such as differential transformers or E-Coil pickoffs, are extremely difficult to zero due to the large residual null voltage composed of signal and harmonics from the source as well as harmonics generated in the transducer. Figure (12) shows a system in which a precise inphase balance can be achieved in the

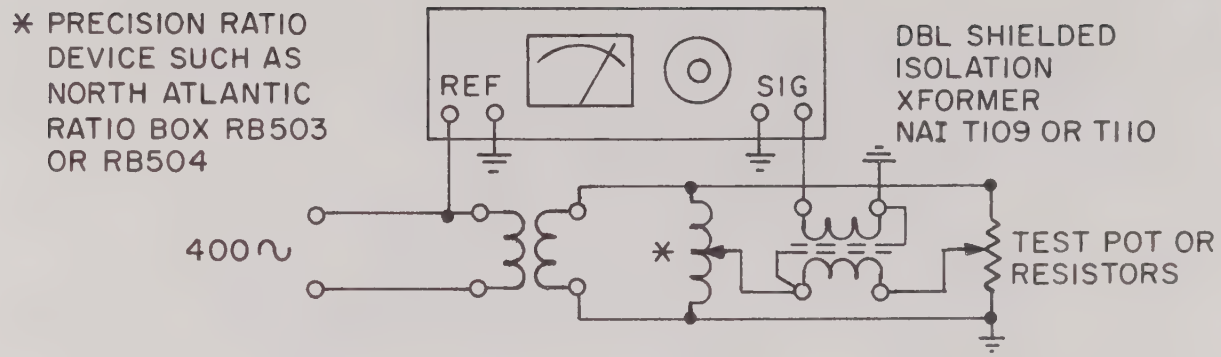

* PRECISION RATIO DEVICE SUCH AS NORTH ATLANTIC RATIO BOX RB503 OR RB504
REF
SIG
DBL SHIELDED ISOLATION XFORMER NAI T109 OR T110
400∿
TEST POT OR RESISTORS

Figure 10. Precision Ratiometer

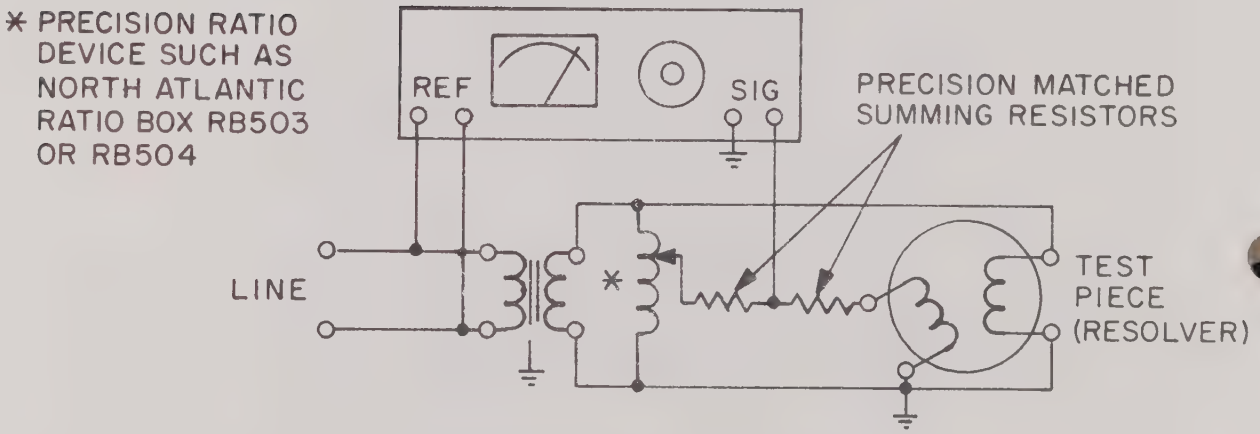


Figure 11. Precision Ratiometer Alternate

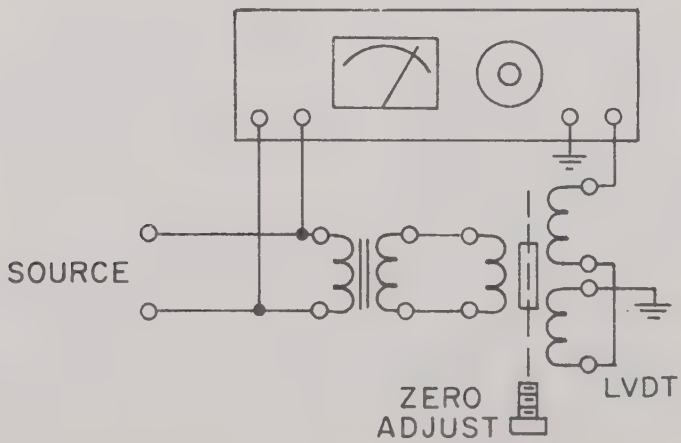


Figure 12. Transducer Nulling

presence of quadrature and harmonics equal to 10 times the full scale sensitivity used. An order greater accuracy in nulling is easily achieved over conventional nulling circuits.

In addition, phase compensation for servo systems or for purposes of linearity compensation are easily accomplished using variations of this same test set-up.

8.8.3 SYNCHRO BRIDGE NULL DETECTOR.

When measuring the electrical errors of synchros, a circuit such as that shown in Figure (13) is used. The phase sensitive characteristics of the Phase Angle Voltmeter as well as the harmonic rejection of the filters and detector makes possible nulls obtainable by conventional instrumentation.

8.8.4 MAGNETIC AMPLIFIER AND THYRATON CIRCUIT ALIGNMENT.

Circuits using thyratron power stages or magnetic amplifier stages cannot be monitored using conventional instruments because measurement errors can be prohibitively large due to the chopped waveforms. If the Phase Angle Voltmeter is used to monitor the output of such devices as shown in Figure (14) the task of alignment for maximum torque or output is straightforward since the meter reading is equivalent to motor output.

8.8.5 CARRIER CIRCUITS AND AMPLIFIERS.

Circuits such as those used for phase compensation, summing circuits, amplifiers, etc., must frequently be aligned to reduce quadrature effect to an acceptable minimum and to establish transfer functions at precise values of Phase Angles. Figure (15) is a test setup used to check the phase angle transfer characteristic of a 400 cps carrier amplifier. Switch, S1, is used to adjust exactly the 90 degree point. A precision of trim to a fraction of a degree can be obtained.

8.8.6 TRANSFORMATION RATIO.

Numerous circuit arrangements are used in making transformation ratio measurements. Two of the most practical are shown in Figure (16a) and (16b).

8.8.6.1 SUMMING NETWORK TECHNIQUES. In Figure (16a) the output of the test piece is arranged to have a polarity opposite to that of the ratio device. By means of precision summing resistors - the outputs are added. At null the ratio device will then read the in-phase ratio of the item under test. In this particular test setup a line isolation transformer is utilized so as to avoid grounding one side of the line. For illustrative purposes the NORTH ATLANTIC P203 PLUG-IN UNIVERSAL ISOLATION MODULE is also shown as providing circuit isolation on the reference input. This feature can also be built into the voltmeter.

In using the circuit of Figure (16a) care should be exercised in evaluating the errors which can arise due to loading of the test piece by the summing resistors and inaccurate summing due to test piece source impedance.

Phase angle is easily measured using the technique shown in the following section for small angle measurement. Allowance must be made in this case for the 2:1 change in voltmeter sensitivity resulting from the summing network.

8.8.6.2 BRIDGING TRANSFORMER TECHNIQUE.

For greater accuracy, the circuit of Figure (16b) has found wide acceptance where the requisite polarity arrangement is feasible. In this case, matching of the test piece output to the ratio device is achieved by using a bridging transformer. A NORTH ATLANTIC P203 UNIVERSAL ISOLATION MODULE is shown, although any good double-shielded isolation transformer with suitable common-mode rejection and low input capacitance would suffice.

Measurement errors in Figure (16b) can occur due to capacitive loading of the test piece or capacitive coupling of the common mode signal into the secondary. The former can be minimized where shielded cables are used by using the so called "driven shield" technique shown in the Figure.

Common-mode rejection is a function of the transformer shielding, the impedance level of each input to the transformer and the relative values of these impedances. Each setup must be judged by itself as to its suitability for a particular measurement.

Phase angle again is easily measured using the small angle measuring technique shown in the following section. Here allowance must be made for the bridging transformer transformation ratio (1:1 for the NORTH ATLANTIC P203 MODULE).

Both of the above measuring systems are used to provide a direct reading of in-phase ratio. Transformation ratio is by definition the ratio of the absolute magnitude of the secondary to primary voltage. To obtain "transformation ratio" the "in-phase" ratio must be divided by the cosine of the phase shift angle.

Maximum accuracies for both setups required that the Phase Dial be adjusted to compensate for residual phase shifts arising from the various transformers in the system, etc., This is conveniently done by stepping the ratio device and adjusting the Phase Dial to produce zero output when the

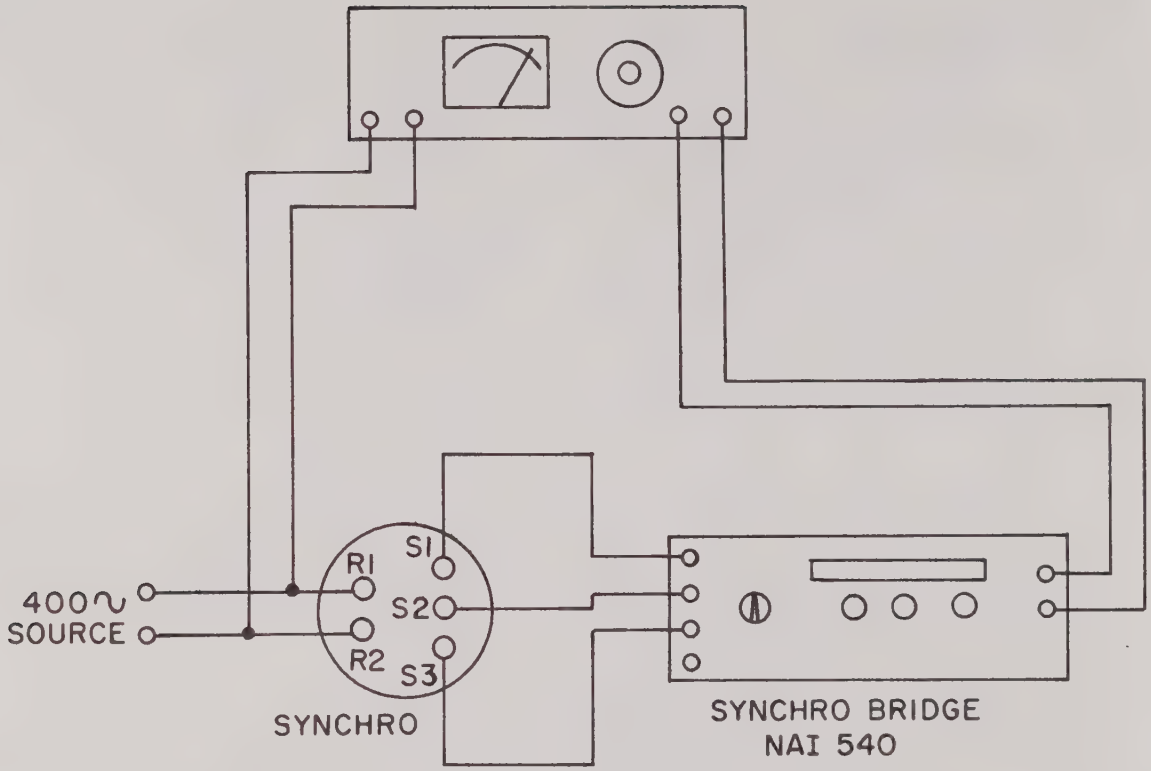


Figure 13. Synchro Bridge Null Detector

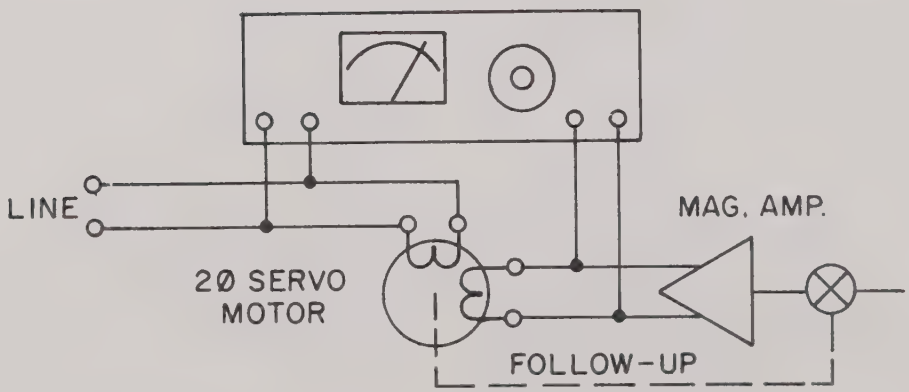


Figure 14. Magnetic Amplifier Alignment

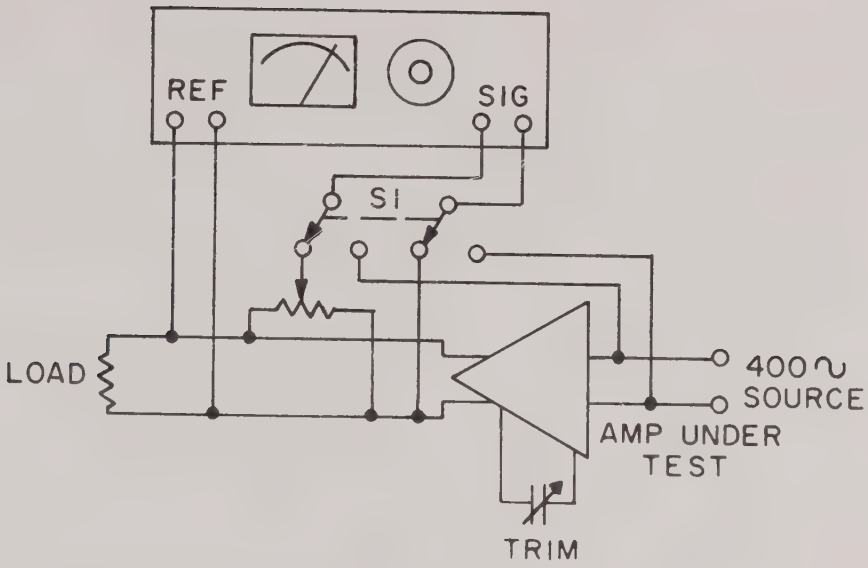


Figure 15 Phase Angle Measurement of Carrier Amplifier

Function Selector is in the 90° position. Operation will then be correct when the Function Selector is returned to the 0° position.

8.8.7 SMALL ANGLE MEASUREMENTS.

Small angle measurements to better than .01° can also be made using the setups of Figure (16). The process consists of making the in-phase null, described in the foregoing, using the precision ratio device. Then, by definition the phase shift angle a is:

$$a = \text{Tan}^{-1} \frac{\text{E Input (quadrature)}}{|\text{E sec}|}$$
$$= \text{Tan}^{-1} \frac{\text{(E Input (quadrature)}}{|\text{E pri}| \times \text{Ratio}}$$

By measuring the magnitude of the secondary voltage and the quadrature component of the input signal, the angle a can be determined.

For Example:

Measured quadrature = 30.00 millivolts

Secondary voltage = 30 volts

$$a = \text{Tan}^{-1} \frac{0.03}{30}$$
$$\cong \frac{0.03}{30} = 0.001 \text{ Rad}$$
$$\equiv 0.001 \times 57.3 = .057 \text{ degrees}$$

8.9 PHASE ANGLE GENERATION.

It is frequently required to generate two voltages with a precisely known phase relationship with respect to each other. Described below are three techniques that will provide accurately phase shifted signals.

8.9.1 MODEL 350 PHASE GENERATOR AND MODEL 351 PHASE CALIBRATOR.

The Model 350 Phase Generator is a completely passive phase shifter. See Figure (17).

It operates on the well-known principle of a resolver-type phase shifter. The reference signal is phase shifted through a precision 90° RC network and this signal $E\underline{/90°}$ is applied to a trigonometrically tapped (sine) transformer divider. The reference signal $E\underline{/0°}$ is applied to another trigonometric (cosine) divider, but only after being attenuated to the same magnitude as $E\underline{/90°}$. The outputs of the two dividers are then combined in a summing transformer which also provides output isolation. The dividers are tapped to permit selection of all trigonometric voltages between $E\underline{/0°}$ and $E\underline{/90°}$, such that the summed output is $E\underline{/a}$ where a is the setting of the front panel dials. A convenient four-position quadrant switch permits generation of any angle from 0° to 360°.

The output angle $a = \tan^{-1} \frac{\sin\theta}{\cos\theta} = \theta$ if $E\underline{/0°} = E\underline{/90°}$

The output amplitude =

$$\sqrt{(E \sin\theta^2) + (E \cos\theta)^2} = E$$

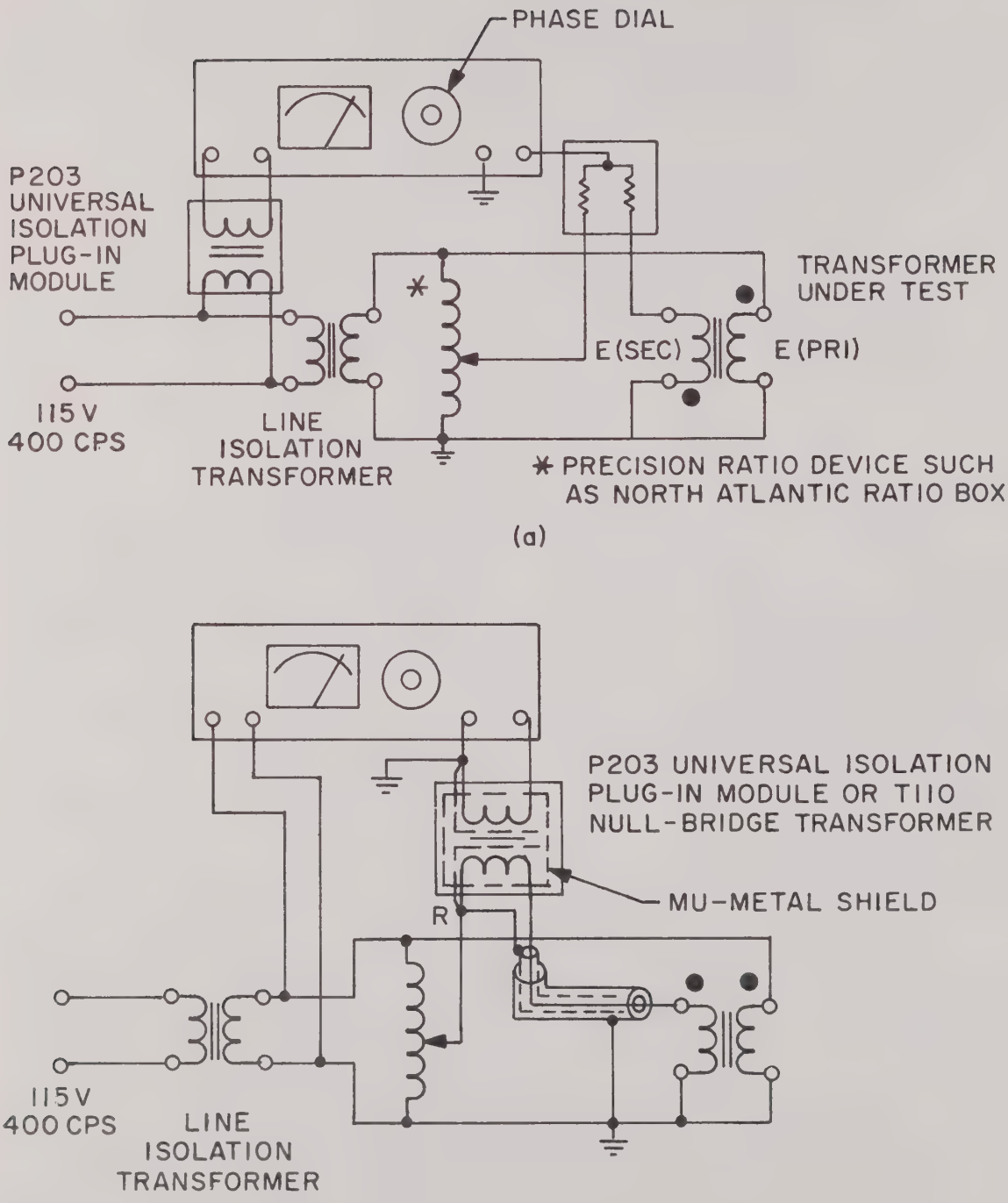


Figure 16. Transformation Ratio Measurement

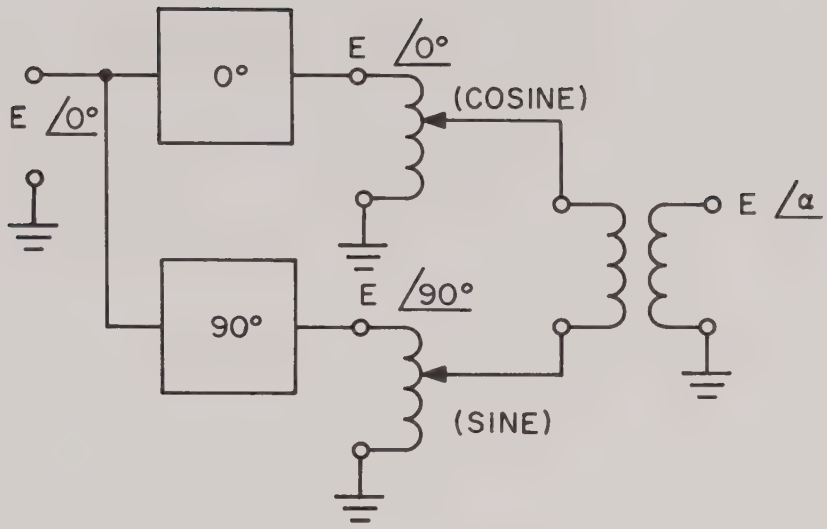


Figure 17 Model 350 Phase Generator, Functional Schematic

The Model 351 Phase Calibrator is used where maximum precision is desired in the presence of harmonics. It is used to set the magnitudes E/0° and E/90° to be equal. In addition, the Phase Calibrator contains an amplifier which raises the Model 350 output from 30mV to 10V. Provision is also made to permit use of an external amplifier where higher voltage levels are desired.

Provision is made to remove the nominal test system phase shift through the use of ±4° angle offset controls on the Model 350 Phase Generator.

The Model 350 Phase Generator may be used with or without the Model 351 Phase Calibrator. All interconnections between the two chassis are made by means of a cable provided with the Model 351 Phase Calibrator.

8.9.2 RATIO BOX PHASE SHIFTER. See Figure (18).

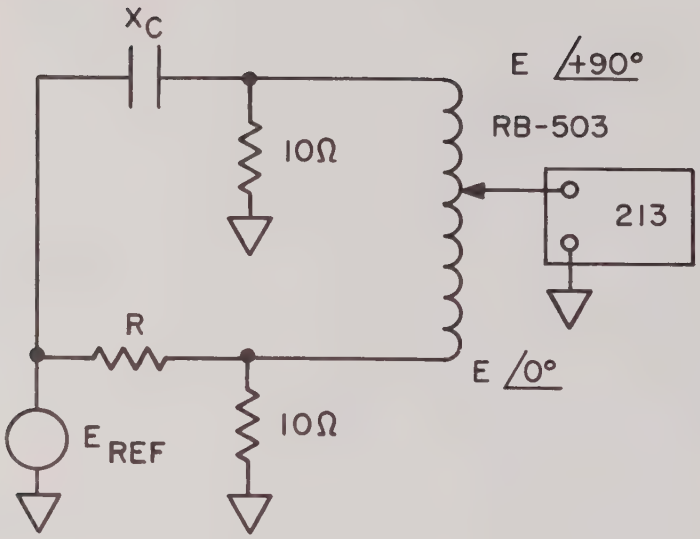
This circuit is somewhat less complicated than the previous circuit in that it requires only a precise 0° and 90° signal be generated by use of passive networks, but it does require a Model RB-503 Ratio Box. Resistors should be of a type having a small reactive component such as metal-film. The capacitor should have a small dissipation factor such as polystyrene. It may be seen that any angle between 0° and 90° can be selected depending on the setting of the Ratio Box. It should be noted, however, that the amplitude of the 0° and 90° signal should be set equal to each other. The output amplitude will vary through a minimum of 0.707 of the 0° and 90° signals at 45° (Ratio Box setting of 0.5).

Phase network component values and Ratio Box settings are determined by the equation shown.

If this equipment is not available, it is suggested that the following methods be used:

8.9.3 RC PASSIVE PHASE SHIFTER. See Figure (19).

Precise phase angles can be generated using the circuit configuration shown below. These networks are very useful and are simple to construct. They do require, however, accurate measurement of component values. They may be constructed with the aid of the design equations shown in Figure (19). The components should be high quality, stable devices; such as mica, or polystyrene capacitors, and metal film or deposited carbon resistors.



$\frac{X_C}{10} \geq 1000$

$R = X_C$

E ∠0° AND E ∠90° MUST BE SET EQUAL WITHIN 1/4%

RATIO BOX SETTING =

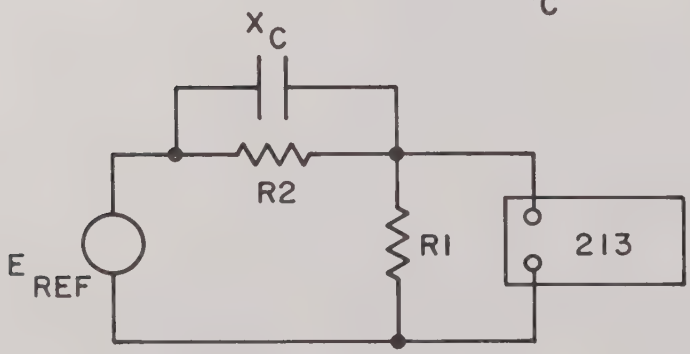
$\frac{1}{1+CTN\ \theta}$ WHERE θ IS DESIRED PHASE SHIFT

Figure 18 Ratio Box Phase Shifter

ATTENUATION = $\frac{R_1}{|Z|}$

PROVIDING $R_1 \angle\angle |Z|$

PHASE SHIFT = $TAN^{-1} \frac{R_2}{X_C}$



$Z = \frac{R_2}{1 + j \frac{R_2}{X_C}}$

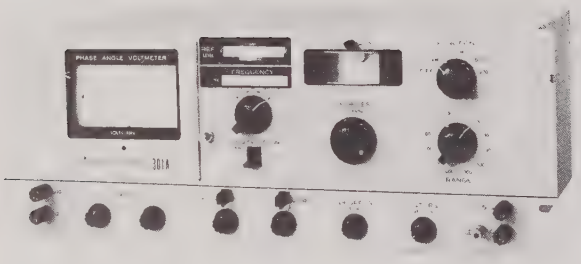
$Z = \frac{R_2 X_C \sqrt{X_C^2 + R_2^2}}{X_C^2 + R_2^2}$

Figure 19 RC Passive Phase Shifter

8.10 APPENDIX

EVOLUTION OF THE
PHASE-ANGLE
VOLTMETER

Evolution of the Phase-Angle Voltmeter



ARTHUR FREILICH
North Atlantic Industries, Inc.

reprinted from Instruments & Control Systems

THE VTVM WAS developed before World War II in order to add versatility to the simple d'Arsonval moving coil meter. Vacuum tube circuits raised meter input impedance by orders-of-magnitude; reduced errors caused by source loading. High gain coupled with closed-loop feedback permitted precise operation over wide frequency bands with high sensitivity.

Fig. 1 shows a simplified version of the ordinary vacuum tube voltmeter. Basic elements include an amplifier or gain stage, a rectifier to convert AC signals into meter drive currents, and finally, a d'Arsonval meter calibrated to read the input voltage directly.

Filtering—Most VTVMs use a moving coil meter that responds to the average value of rectified input signal. However, the RMS value of a sinusoidal signal is 1.11 times higher than the average value: thus, an RMS-reading VTVM is scaled to read 1.11 times the actual average value of voltage being measured.

This relationship of RMS = 1.11 x AVERAGE only holds true if the input is a sinewave voltage. If it is not, a new scale factor must be used depending upon the actual waveshape.

In many measuring applications the VTVM is equipped with a filter to take out the harmonics from the input signal (Fig. 2). If the filter can be switched in and out of the measuring circuit, the VTVM will have "fundamental" and "total" voltage measuring modes. This is useful in measuring amplifier distortion. Assuming that pure sinewaves are fed to the amplifier's input from a quality signal generator, then the difference between separate readings for "total" and "fundamental" output voltages is a measure of the harmonic content (distortion) in the amplifier's output.

The next step towards the phase-angle voltmeter roughly doubles circuit complexity by addition of a second amplification channel for reference signals.

Phase sensitive voltmeters (PSVM) give information about the vector components into which an AC signal may be resolved (Fig. 3).

The PSVM depends upon both input signal amplitude, and the degree to which the input signal "overlaps" or coincides "in time" with the reference.

The ability to measure according to signal overlapping, or coincidence, depends on a special rectifier, called a phase-sensitive demodulator (Fig. 4), which is controlled by the reference signal.

Phase Sensitive Demodulators — The phase sensitive demodulator differs from conventional rectifiers in that no signal path is available between input source (amplifier) and output load (meter) until the reference voltage drives the demodulator into conduction. An ordinary rectifier breakdown voltage is typically around 0.5 to 1.0 volts.

Phase sensitive demodulators can pass signals of both polarities once the reference voltage has established the conduction path. A rectifier's function is precisely the opposite; it can pass only unidirectional signals. The ordinary rectifier may be regarded as a special case of phase-sensitive demodulation in which the input signal is always in phase with the demodulator turn-on signal.

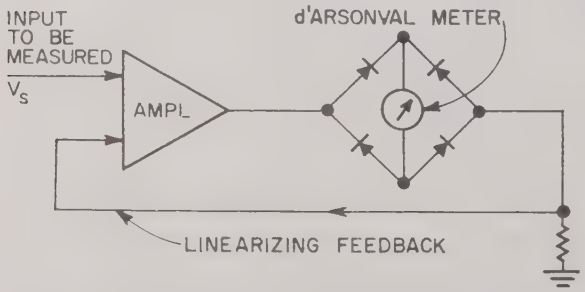


FIG. 1. VTVM raises input impedance of d'Arsonval meter, and increases sensitivity, permitting wideband operation.

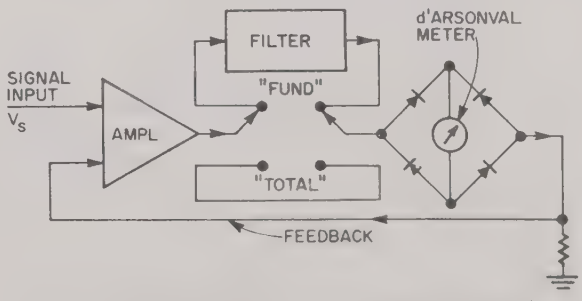


FIG. 2. FILTER allows meter to measure fundamental and total input volts.

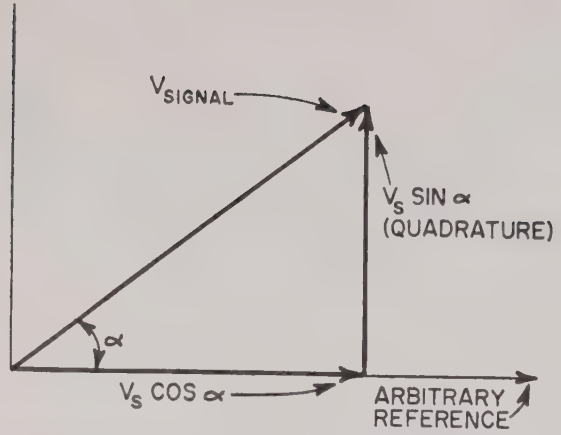


FIG. 3. ANY AC signal may be resolved into in-phase and quadrature components with respect to an arbitrary reference.

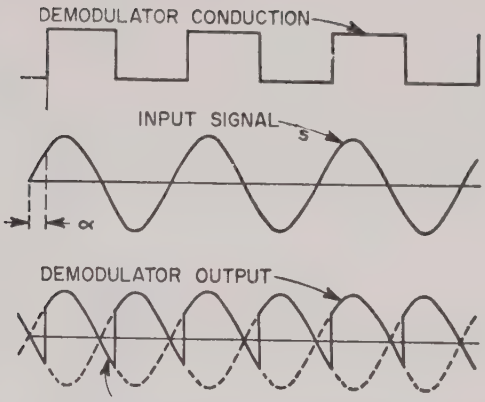


FIG. 5. DEMODULATOR output depends upon phase angle, or "overlap," between input signal and demodulator conduction period. Reference input determines conduction period.

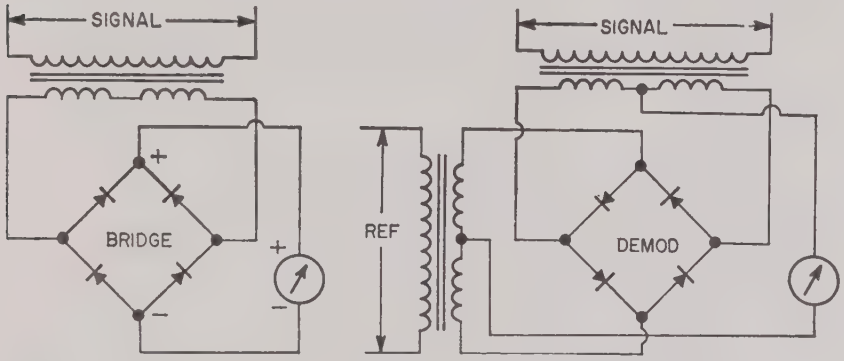


FIG. 4. CONVENTIONAL rectifier, left, passes signal to the meter whenever input voltage rises above breakdown voltage of diodes. Phase sensitive demodulator, right, passes signals only when reference input drives diodes into conduction.

Owing to the demodulator's ability to conduct in both directions it is possible for the meter to read zero even though the input signal has maximum amplitude.

For example, if the input and reference signals are exactly 90° out of phase, the signal crosses through zero and reverses polarity exactly at the mid-point of each demodulator conduction period. An oscilloscope connected to the meter terminals would show equal periods of positive and negative potential applied to the meter for every demodulator conduction period. A moving coil meter due to its considerable inertia, has a maximum response frequency of about 2 Hz. The meter, unable to follow rapid reversals of polarity, responds to the average input power. Since both the positive and negative signal components are equal and have identical waveforms (assuming no harmonics), their algebraic sum is zero, and the meter reads zero when input and reference are 90° out-of-phase.

The demodulator output and meter reading are related to input and reference voltage (Fig. 5) by $V_M = K\,V_s cos\,\alpha$, where V_M is the meter reading, K is a calibration constant involving meter sensitivity (ratio of RMS to average, and the amplifier gain), V_s is the input voltage, and α is the phase angle between input signal and reference. This relationship stems from the meter's ability to time-integrate the demodulator output and respond only to its average value:

$$\text{Thus, } V_M = K\int_{0}^{\pi} V_s \sin(\omega t + \alpha)\,dt - K\int_{\pi}^{2\pi} V_s \sin(\omega t + \alpha)\,dt$$

$$= K\,V_s \cos\alpha$$

The component $V_s cos\,\alpha$ is seen from Fig. 3 to represent the component of input signal V_s, resolved in phase with the reference.

Phase Sensitive Voltmeter—The PSVM (Fig. 6) has two amplifier channels, which feed the signal and reference inputs into separate terminals of the demodulator.

The PSVM also measures the quadrature component of input voltage, represented in Fig. 3 as $V_s sin\,\alpha$, as well as the in-phase voltage, $V_s cos\,\alpha$. Measurement of quadrature voltage ($V_s sin\,\alpha$) is based on the demodulator's ability to develop a reading proportional to the cosine of the angle, α, between input and reference, given by $V_M = V_s cos\,\alpha$. By switching a precise 90° phase shift network into the reference channel, total phase shift between signal and reference is given ($\alpha - 90°$). Meter reading remains a function of phase angle, and is given by $V_M = V_s cos\,(\alpha - 90°)$. But from simple trigonometric identities, Cos ($\alpha - 90°$) = Sin α. Therefore, by introducing additional 90° phase shift between input and reference signals, meter reading is converted from $V_M = V_s cos\,(\alpha - 90°)$ to $V_M = V\,sin\,\alpha$. This is a reading of quadrature voltage.

Noise is cancelled through a combination of the meter's high inertia and the demodulator's ability to pass both positive and negative noise components. If the noise is truly random, there will be equal amounts of positive and negative noise power fed to the meter during each conduction period.

Harmonic Cancelling—The demodulator cancels harmonics by summing positive and negative harmonic

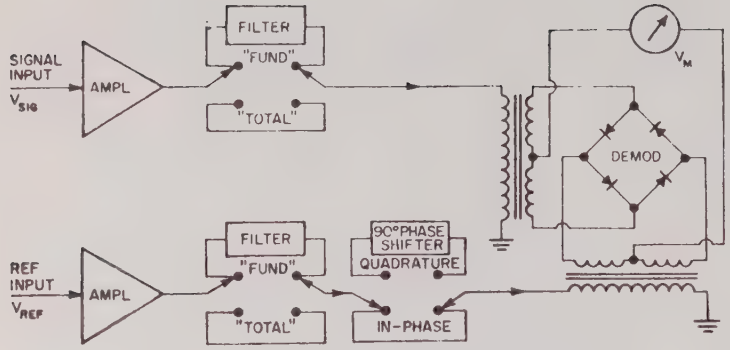


FIG. 6. PSVM drives demodulator with reference and input signal to measure in-phase and quadrature components of input signal. Meter also measures total and fundamental input voltages.

components in the slow-responding meter movement so that the average harmonic content is partly or wholly neutralized. For example, there are three full cycles of the sixth-order harmonic during each half cycle of the signal fundamental, hence, an equal number of positive and negative half-cycles of sixth-harmonic are fed to the meter. These even-order harmonics cancel themselves out, leaving the meter to respond only to the fundamental. Odd order harmonics do not cancel exactly, because there is always one half-cycle of odd-order component left over. However, one remaining half-cycle of say 11th order harmonic, means that the ten other harmonic half-cycles that occurred during the fundamental half period were cancelled out. That is, the demodulation process reduces odd-order harmonics to a fraction given by the actual order of that harmonic. Fifth order harmonics are reduced fivefold, seventh order harmonics are reduced by a factor of seven, etc. (Fig. 7.)

The Phase-Angle Voltmeter—One step beyond the phase sensitive voltmeter's capability is needed if an AC signal is to be completely specified. This is a provision for measuring phase angle, α, between input signal and reference. The phase-angle voltmeter (PAVM) (Fig. 8) differs from the PSVM by embodying a precise, calibrated, broadband phase shift network that reads out phase angle directly.

It is possible to calculate phase angle, α, from readings of in-phase and quadrature voltage, $V \cos \alpha$, and $V \sin \alpha$. ($\tan \alpha = V \sin \alpha / V \cos \alpha$.) However, phase measuring accuracy is limited by the accuracy to which the voltages can be measured.

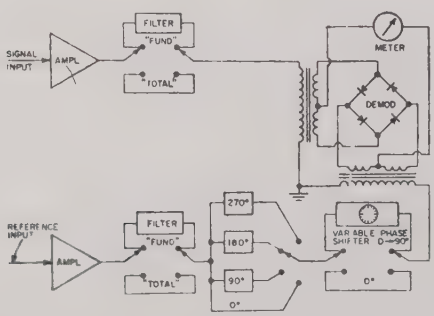


FIG. 8. PAVM measures phase angle, quadrature voltage, in-phase voltage, total voltage and null voltage.

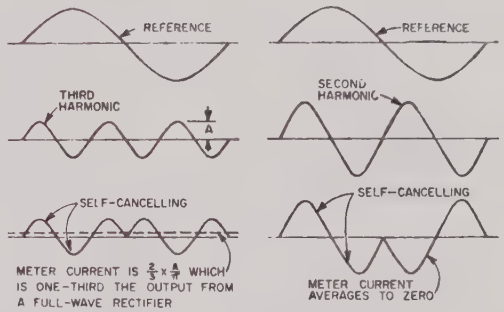


FIG. 7. DEMODULATION reduces odd-order harmonics.

Phase angles may be measured directly to ¼° accuracy over the PAVM's full 0 to 360° range. The principle of phase angle measurement lies in using the meter to measure the quadrature component of input voltage, then observing the amount of additional phase shift required to make the quadrature voltage disappear.

To make the measurement, the instrument is switched to its quadrature-reading mode (a fixed 90° phase-shift network is introduced into the reference channel) and the quadrature voltage read on a coarse scale. Next, the calibrated phase shift network in the reference channel is adjusted to reduce the quadrature voltage towards zero. Instrument sensitivity is progressively improved by switching to lower voltage ranges, until the desired accuracy has been achieved. The phase-shift-dial reading is then the actual phase difference between input and reference.*

Null Measurements—Besides measuring total, fundamental, in-phase, and quadrature voltages, as well as phase angles, the phase angle voltmeter also makes an excellent null detector. Here, the variable phase shifter provides subtle but important advantages for null detection that even the phase sensitive voltmeter used as a null detector cannot provide. One particularly useful advantage of the phase shifter is its use in A.C. Bridge work, where, by proper positioning of the phase dial, the interaction between the bridge's balancing controls can be eliminated.

* It would be equally valid to measure phase angle by adjusting the phase dial for maximum in-phase voltage instead of minimum quadrature voltage, but null voltages (voltage minima) can be read more precisely than voltage maxima.

WARRANTY

A. The Seller warrants Products against defects in material and workmanship for one year from the date of original shipment. The Seller's liability is limited to the repair or replacement of Products which prove to be defective during the Warranty period. There is no charge under the Warranty except for transportation charges. The Purchaser shall be responsible for Products shipped until received by the Seller.

B. The Seller specifically excludes from the Warranty 1) calibration, 2) fuses, and 3) normal mechanical wear, eg, end-of-life on assemblies such as switches, relays, gear trains, etc. is dependent upon number of operations or hours of use, and end-of-life may occur within the Warranty period.

C. The Seller is not liable for consequential damages or for any injury or damage to persons or property resulting from the operation or application of Products.

D. The Warranty is voided if there is evidence that Products have been operated beyond their design range, improperly installed, improperly maintained or physically mistreated.

E. The Seller reserves the right to make changes and improvements to Products without any liability for incorporating such changes or improvements in any Products previously sold, or for any notification to the Purchaser prior to shipment. In the event the Purchaser should require subsequently manufactured lots to be identical to those covered by this Quotation, the Seller will, upon written request, provide a quotation upon a change control program.

F. No other Warranty expressed or implied is offered by the Seller other than the foregoing.

CLAIMS FOR DAMAGE IN SHIPMENT

The purchaser should inspect and fuctionally test the Product(s) in accordance with the instruction manual as soon as it is received. If the product is damaged in any way, including concealed damage, a claim should be filed immediately with the carrier, or, if insured separately, with the purchaser's insurance company.

SHIPPING

On products to be returned under warranty, await receipt of shipping instructions, then forward the instrument prepaid to the destination indicated. The original shipping containers with their appropriate blocking and isolating material is the preferred method of packaging. Any other suitably strong container may be used providing the product is wrapped in heavy paper or a plastic bag and surrounded with at least four inches of shock absorbing material to cushion firmly, preventing movement inside the container.

NOTES

NOTES

WARRANTY REGISTRATION

Please complete and mail this Warranty Registration Card without delay. Placing this Registration on file with our Service Department will assure that you receive applicable service data as issued. No postage is required. (Mailed on_____ by_____)

WARRANTY REGISTRATION

Date _____

Please register _____

Model No. _____ Serial No. _____

under the terms of the warranty stated in this Instruction Manual.

Name _____

Title _____ Dept. _____

Company _____

Address _____

City _____ State _____ ZIP _____

Calibration and maintenance responsibility has been assigned to the following person and/or department. Address applicable service data to (if same as above, please state):

Name _____

Title _____ Dept. _____

For our information please indicate:

Condition of instrument on receipt _____

Application _____

Will the instrument be: resold as part of a system? _____

maintained as company equipment? _____

SERVICE INFORMATION

This card is provided to aid you in obtaining prompt assistance with questions you may have regarding operation, calibration, maintenance or service parts for your North Atlantic instrument. State information desired and mail. No postage is required.

SERVICE INFORMATION REQUEST

Instrument _____

Model No. _____ Serial No. _____

We require the following service information: _____

_____

_____

_____

_____

Name _____ Title _____

Company _____ Dept. _____

Address _____

City _____ State _____ ZIP _____

Phone _____ Ext. _____

SERVICE INFORMATION

This card is provided to aid you in obtaining prompt assistance with questions you may have regarding operation, calibration, maintenance or service parts for your North Atlantic instrument. State information desired and mail. No postage is required.

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_____

_____

_____

Name _____ Title _____

Company _____ Dept. _____

Address _____

City _____ State _____ ZIP _____

Phone _____ Ext. _____

(please send additional Service Information Request cards)

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